DEVELOPMENT OF CONTROLLED IMPULSE TECHNIQUE FOR IN SITU TESTING OF ROCK

Francis X. Cannaday
G. M. Leo

Bureau of Mines
U.S. Department of the Interior
Denver, Colorado
Contract AF 29(601)-64-PO-10

TECHNICAL REPORT NO. AFWL-TR-65-156

February 1966

AIR FORCE WEAPONS LABORATORY
Research and Technology Division
Air Force Systems Command
Kirtland Air Force Base
New Mexico

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FOREWORD

This report was prepared by the Bureau of Mines, U.S. Department of the Interior, Denver, Colorado, under Contract AF29(601)64-PO-10. The research was performed under Program Element 7.60.06.01.D, Project 5710, Subtask 13.144, and was funded by the Defense Atomic Support Agency (DASA). Inclusive dates of research were June 1964 to July 1965. The report was submitted in December 1965 by the AFWL Project Officer, Captain Joseph J. O'Kobrick (WLDC). Captain Thomas E. O'Brien (WLDC) served as Project Officer from June 1964 to July 1965.

Research, design and manufacture of new or special equipment was done by Bureau personnel and facilities. Field sites for testing were made available by the courtesy and cooperation of the Colorado School of Mines, the International Minerals and Chemical Corporation, and the Magma Copper Company. In addition to field sites, these organizations supplied necessary maps, services, and help required for preparation of test stations, including the drilling of holes in some cases.

This report has been reviewed and is approved.

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ABSTRACT

Object of the work is development of equipment and techniques for
transmission of nondestructive, repetitive, stable, closely con-
trolled-shape sonic pulses through various types of rock in place.
Rock masses tested were granitic gneiss schist, potash rich salt
beds, and porphyry-copper ore. The tests measure some physical
properties of a rock mass over various periods of time. Sonic
pulses are produced by electronically excited, piezoelectric-ceramic
transducers housed in transmitter and receiver units. Electronic
pulses for transducer excitation are generated by transistorized
battery-powered pulse generators. Output from receiver units
(or geophones), amplified by transistorized preamplifiers, is led
into a portable transistorized oscilloscope triggered by the elec-
tronic pulse generator to display the signal. Various models of
transmitter and receiver units differing in size, weight and manner
of insertion into boreholes in rock are described. Two models of
electronic pulse generators and a receiving unit preamplifier are
described. With exception of the oscilloscope, all major equipment
components were developed by U. S. Bureau of Mines facilities.
Transmission distances attained varied from 55 feet in strongly
hydrothermally altered porphyry copper ore to 1,373 feet in sylvite-
halite. Data obtained could be used to compute dynamic moduli of
rigidity and elasticity. Under proper conditions, data were obtained
that revealed development or presence of permanent rock-structure
damage.

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CONTENTS

CONTENTS (Continued)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONTINUED)

viii

LIST OF ILLUSTRATIONS (CONTINUED)

LIST OF TABLES

SECTION I

INTRODUCTION

The purpose of this work is to continue and expand the investigation into the use of piezoelectric pulsing equipment for in situ sonic testing for elastic physical properties or for changes in physical properties of physical condition of rock masses at different times.

Research in rock mechanics and related subjects has shown repeatedly that in many instances tests must be carried out on a rock mass in place to get physical data which are applicable to the rock mass. Tests on laboratory size samples often yield data which differ from in-situ test data. The discrepancy usually becomes greater as the laboratory samples tested become smaller.

To obtain data on changes in the physical condition and/or properties which a rock mass may be undergoing, tests must be performed in situ.

Sound transmission through rock in place may be used as a test for some physical properties and as an indicator of changes that may be occurring in the rock. The rock sample under test is that portion of rock mass through which the sound is transmitted. Range of transmission is governed by geometrical considerations of equipment emplacement, and is limited by equipment capabilities for a given kind of rock mass. By transmitting through suitably large distances, data can be obtained which are more nearly representative either for a whole rock mass, or for a local portion only of a rock mass, as desired.

The usual sonic testing field methods use mechanical blows or explosives to introduce sound energy into the rock. As compared to these field techniques, piezoelectric pulsing in situ permits a regularly repetitive, tightly controlled, stable pulse shape to be introduced into the rock without damage to the rock. These features make the technique well suited for tests underground, at selected stations over suitable periods of time. Furthermore, the method can compare the controlled sonic energy introduced into the rock mass with the

sonic energy that emerges at a receiving point. Other methods with little control over the introduction of sonic and ultrasonic energy into the rock mass (explosions, blows) do not have this capability.

Previous work done by the U. S. Bureau of Mines in the use of piezoelectrically excited sonic pulse transmissions through rock in situ is covered by U. S. Bureau of Mines Report of Investigations, RI _____ (Ref. 1) which describes transmission through as much as 57 feet of granitic gneiss schist, in underground mine workings. The present work showed a need for in situ testing of the technique on other rock types, and need for making more powerful, sensitive and flexible equipment.

The major objective of this report is the development of highly portable equipment and of techniques that have expanded coverage in three different rock types in situ.

SECTION II

GENERAL CONSIDERATIONS

Mathematical Relationships

The relationship between the various moduli of elasticity and sound propagation in an elastic behaving material has been discussed elsewhere (2, 3, 4). The basic formulas are:

$$E = dC_\ell^2 , \tag{1}$$

$$Y_b = dC_b^2 , \tag{2}$$

$$Y_s = dC_s^2 , \tag{3}$$

$$C_b = C_\ell \sqrt{\frac{1-m}{(1+m)(1-2m)}} , \tag{4}$$

$$C_s = C_\ell \sqrt{\frac{1}{2(1+m)}} , \tag{5}$$

$$m = \frac{1}{2}\left(1 - \frac{C_s^2}{C_b^2 - C_s^2}\right) , \text{ obtained from eq. (4) and (5)} \tag{6}$$

where

   C_ℓ = Slender-bar longitudinal wave velocity,

   C_b = Bulk-wave velocity, (longitudinal wave, P wave)

   C_s = Shear-wave velocity, (transverse wave, S wave)

   d = Density,

   E = Modulus of elasticity, (Young's modulus)

Y_b = Stiffness modulus,

Y_s = Modulus of rigidity, (shear modulus) and

m = Poisson's ratio.

Data collected yields C_b, C_s, and d.   Young's modulus, E, is usually the quantity computed.

Rock Types Tested

Three rock types were selected for tests: Granitic gneiss schist, potash rich salt beds, and porphyry-copper ore.

Tests in granitic gneiss schist were conducted at the Colorado School of Mines Experimental Mine at Idaho Springs, Colorado.   Main entrance to the mine is through an adit.   The rock mass is in the Idaho Springs formation of Precambrian age.   At the test site, the rock mass is a granitic gneiss containing conspicuous bands rich in hornblende and biotite, occasionally schistose.   Joints are frequent, arranged in several, well defined sets.   Minor faulting is present.   Narrow seams and stringers of pyrite with some galena and occasional sphalerite are found in the rock mass.   Some seams may contain silver and gold values, for which the mine was worked in the past.   The rock mass is a typical "hard rock," and as a whole is considered "good ground," that requires no timbering other than locally.

The mine is conveniently located and facilities are available for preparing test setups.   Mine noise level is frequently at a minimum because activity is intermittent.   The mine has not been active since before 1900, and is now used for training and experimental purposes.   Ground conditions are stable with no major settling or caving in progress.

Tests on potash rich salt beds were conducted at the International Minerals and Chemical Corporation potash mine near Carlsbad, New Mexico.   All tests were conducted at the 900 foot level, approximately 900 feet below the ground surface, in the same sylvite-halite beds.

Tests in "porphyry copper" ore were conducted at the 2,015 grizzly level of the San Manuel mine of the Magma Copper Company at

San Manuel, Arizona. The level is approximately 2,000 feet below
the original ground surface. Detailed descriptions of the ore body,
mine and methods used have been published by various authors, (Refs.
5, 6, 7).

The ore body is a mass 6,800 feet long which, for the exception
of a small outcrop, is covered by up to 1,900 feet of barren Gila
conglomerate. A major fault separates the Gila conglomerate from
the ore body. The ore mass consists essentially of hydrothermally
altered quartz-monzonite and monzonite-porphyry heavily criss-
crossed with multiple fractures usually containing various amounts of
pyrite, chalcopyrite, chalcocite and molybdenite. Because of the
intense fracturing and alteration, mine openings driven in the ore mass
must be artificially supported. Certain sections of the mine are
affected by very "heavy ground" conditions. Wall rock in mine openings
is found in a variably shattered condition to a depth of several feet
from the rock surface. Taken as a whole, the ore body could be con-
sidered somewhat homogeneous. But locally, from mine opening to
adjacent mine opening or even from foot to foot, the rock properties,
structural and otherwise can and do vary radically, giving the impression
of a heterogeneous assemblage of variously jointed pieces of similar
rock in various stages of hydrothermal alteration, ranging from
partial to total.

Because of mining operations, local stress concentrations become
high and are changeable. Noise level is generally high, as the mine is
operated on a 24 hour, 7 day a week basis. Daily output is over 35,000
tons of ore produced by block-caving methods.

Selection of Transducers

A piezoelectric transducer deforms when a voltage is applied to
the transducer electrodes; and conversely, a voltage will appear at
the electrodes if the transducer is deformed. Piezoelectric transducers
are made from relatively large, single, piezoelectric crystals (natural
or artificial) or from masses of small, properly oriented (polarized)
piezoelectric crystals, commonly known as piezoelectric ceramics.
Basic requirement for transducers is the ability to produce a maximum
of mechanical energy from a given input of electrical energy (or vice

5

versa), after all losses are discounted.* The quality is measured as the electromechanical coupling coefficient k, often expressed in percent. The amount of deformation or deflection of a given transducer for a given applied voltage is a constant, d, that can be expressed as strain produced by an electric field. The values of d are usually given in meters per volt.** The voltage generated in response to a deformation-causing stress is another constant, g, which can be expressed as the electric field produced by the stress applied. Values of g are usually given in volt-meters per Newton . # For pulse generation, high values of d are desirable; for reception, high g is desirable. High value for k is desirable for both pulse generation and reception.

In addition to the fundamental piezoelectric requirements, transducers for use in this field work must be structurally rugged, stable, not significantly affected by ambient changes in moisture and temperature, and should be available in various shapes and sizes.

Of the various piezoelectric actions or modes [(a)] available, only the thickness expander circular plate mode was used in this work. This

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*This simplified presentation is taken from technical papers published by or through courtesy of piezoelectric materials manufacturers, (Refs. 8, 9, 10). For more complete information see (Ref. 11).

** $$\frac{\text{Strain produced}}{\text{Field applied}} = \frac{\text{meters/meter}}{\text{volts/meter}} = \frac{\text{meters}}{\text{volt}}$$

\# $$\frac{\text{Field produced}}{\text{Stress applied}} = \frac{\text{volts/meter}}{\text{Newtons/meter}^2} = \frac{\text{volts meters}}{\text{Newtons}}$$

The Newton is a unit of force and is equal to 0.1020 kilograms or 0.2248 pounds.

(a) Type or direction of deformation that takes place upon electrical excitation.

mode is illustrated by a piezoelectric circular plate or cylinder with parallel ends which are silver coated. Because of the manner in which the substance is polarized, each metallized surface or electrode will have a fixed positive or negative polarity.

If an electric charge is applied with the proper polarity to the electrodes, the cylinder or plate will elongate as it simultaneously diminishes in diameter. This deformation persists as long as the charge is maintained between the electrodes. An electric charge applied with reversed polarity decreases length or thickness, and increases the diameter.

Conversely if the cylinder length or plate thickness is reduced by compression, a voltage of proper polarity will appear at the electrodes. On the other hand, lengthening by tension will produce a reversed polarity charge.

Among commercially available, cut crystal types of piezoelectric substances, Rochelle salt is far above the rest in values for piezoelectric constants, k, (as high as 70 percent plus) d and g. *
Nevertheless, Rochelle salt was not selected for use because it is very fragile, is extremely sensitive to moisture, and is affected by temperature variations within the expected operating conditions.

Among the crystals, lithium sulphate has comparatively high k and g constants for the thickness expander mode, which would indicate suitability for pulse reception. Direct experimental comparison of a lithium sulphate unit with ceramic units showed it inferior piezoelectrically, and impractical for reliable field use because of extreme fragility and high susceptibility to moisture.

Commercially available piezoelectric ceramic transducers are basically barium titanate and lead zirconate titanate. For barium

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*
Values for piezoelectric constants as given in this report were taken from manufacturer's specification tables.

7

titanate, k_{33} ** is 46 to 50 percent, d_{33} is 130×10^{-12} to 149×10^{-12} meters/volt and g_{33} is 12×10^{-12} to 14×10^{-12} volt-meters/Newton. Barium titanate is unaffected by high humidity, has an operating temperature of up to 100 degrees Centigrade, is quite rugged and can withstand stresses up to 11,600 psi.

Lead-zirconate titanate ceramics are unaffected by humidity, can operate at 300 degrees Centigrade, are quite rugged, and can withstand relatively high compressive stresses without damage. The form marketed under the trade mark "PZT-4" has a k of 64 percent, d_{33} of 255×10^{-12} meters/volt and g_{33} of 24×10^{-12} volt-meters/Newton. Another formulation of lead zirconate titanate marketed as "PZT-5" has a k of 67.5 percent, d_{33} of 320×10^{-12} meters/volt and g_{33} of 24.4×10^{-12} volt-meters/Newton.

From the data given, lead-zirconate titanate ceramic in the "PZT-5" formulation would be expected to give the best general results, for the requirements of this work. All three ceramics were tested in the field and found satisfactory. The lead zirconate titanate formulation "PZT-5" was most effective as transmitter and most sensitive as receiver. Consequently, lead-zirconate titanate "PZT-5" was used for all optimum range experimentation.

Coupling of Transmitter and Receiver to Rock

When a piezoelectric transmitter coupled to a rock produces a sonic pulse, part of the pulse energy is transmitted across the boundary between transducer and rock, and part is reflected back from the boundary. The amount of energy that crosses the boundary depends on the ratio between the characteristic impedances of the substances on each side of the boundary (Ref. 2, pp. 38, 39). Thus

$$r = \frac{Z_2}{Z_1} \tag{7}$$

**

Subscript 33 indicates thickness expander mode.

where

$$Z_2 = d_2 c_2 \tag{8}$$

$$Z_1 = d_1 c_1 \tag{9}$$

and

   r = impedance ratio at the boundary

   Z_1 = characteristic acoustic impedance for medium on transmitting side of boundary

   Z_2 = characteristic acoustic impedance for medium on receiving side of boundary

   d_1 = density of transmitting medium

   d_2 = density of receiving medium

   C_1 = longitudinal sonic wave velocity of transmitting medium (bulk wave velocity)

   C_2 = longitudinal sonic wave velocity of receiving medium (bulk wave velocity).

When the boundary impedance ratio r is unity all energy incident normally to the boundary crosses the boundary without any reflections; when the impedance ratio is zero all energy is reflected back at the boundary. The relationship is shown by (2, page 43).

$$\alpha_t = \frac{4 r}{(r + 1)^2} \tag{10}$$

where

   α_t = transmission coefficient

   r = boundary impedance ratio.

Transmission coefficient is defined as the ratio of the transmitted intensity to the incident intensity. The graphs in figures 1 and 2 show graphically the transmission coefficients for values of r smaller and

9

greater than one respectively.

Maximum energy transfer would be obtained when r, impedance ratio between transmitting transducer and rock, is unity, a generally unattainable condition in practice.

The practical problem of coupling the unit to rock reduces to the preparation of a smooth surface on the rock itself or on a suitable compound adhered to the rock, for the transmitter or receiver transducer diaphragm to press upon. If the rock is easily amenable to smooth surfacing with a cutting bit (as is the case with rock salt and similar formations), and the transmission coefficient between probe and rock is not less than 0.7, the simplest method is to press the probe diaphragm directly against the prepared, smooth, flat bottom of the drill hole. This method was used in sylvite-halite rock, but not in granitic gneiss or porphyry-copper ore.

For rock that is not easily amenable for the making of a smooth surface at the bottom of the drill hole, a different method was used. A pad made of an appropriate compound and suitable to subsequent smooth-surfacing, was cemented to the bottom of the hole. For transmission from unit to pad, to rock, with respective impedances Z_1 Z_2 Z_3, we have

$$\frac{Z_2}{Z_1} = r_{12} \text{ boundary impedance ratio} \tag{11}$$

and

$$\frac{Z_3}{Z_2} = r_{23} \text{ boundary impedance ratio.} \tag{12}$$

Then, from equation (10) or figures 1 or 2

α_{12} = Intensity transmission coefficient corresponding to r_{12} boundary impedance ratio.

α_{23} = Intensity transmission coefficient corresponding to r_{23} boundary impedance ratio.

10
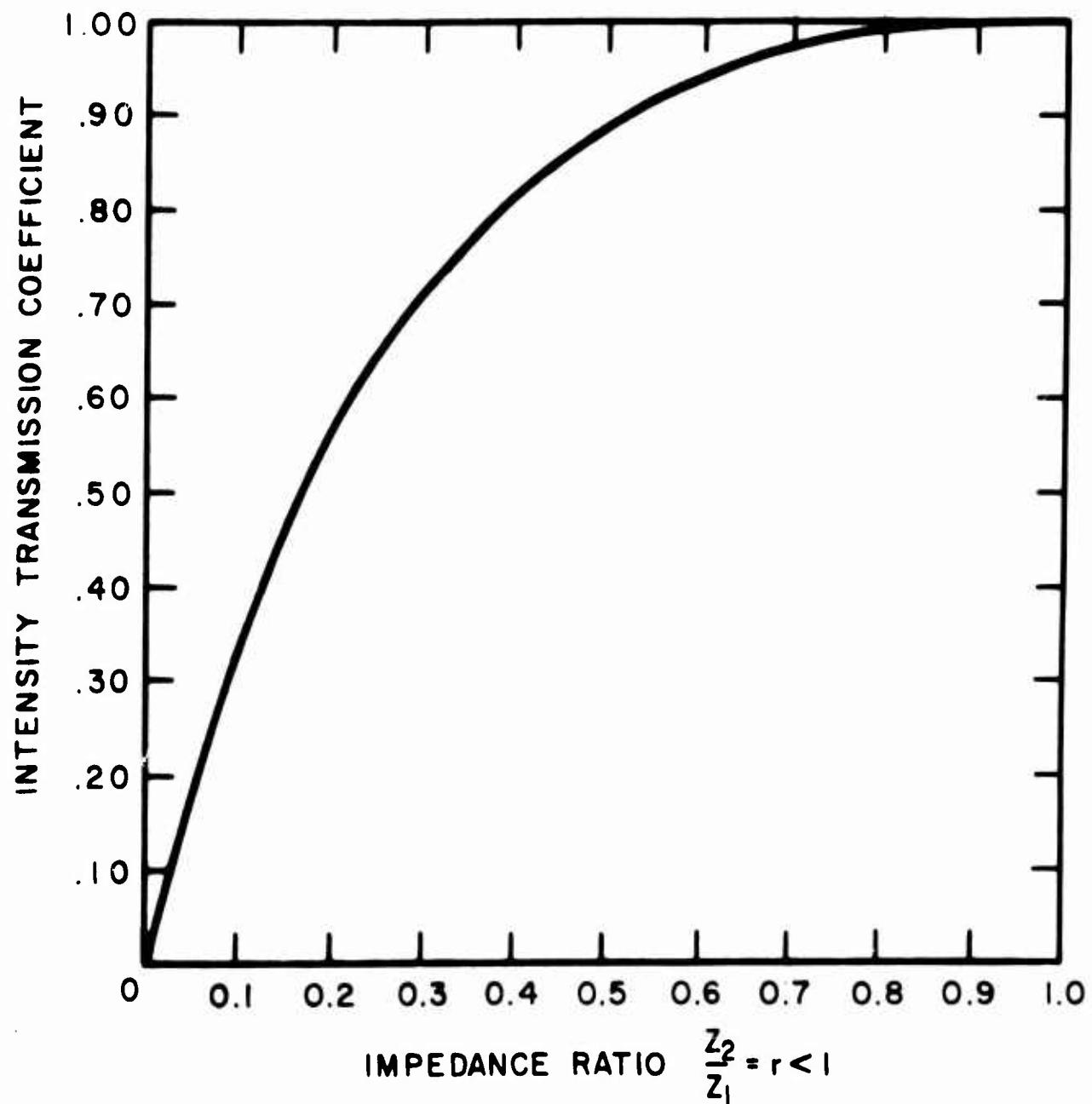
FIGURE   1.-Transmission Coefficient Curve for Impedance Ratios
Smaller Than One.
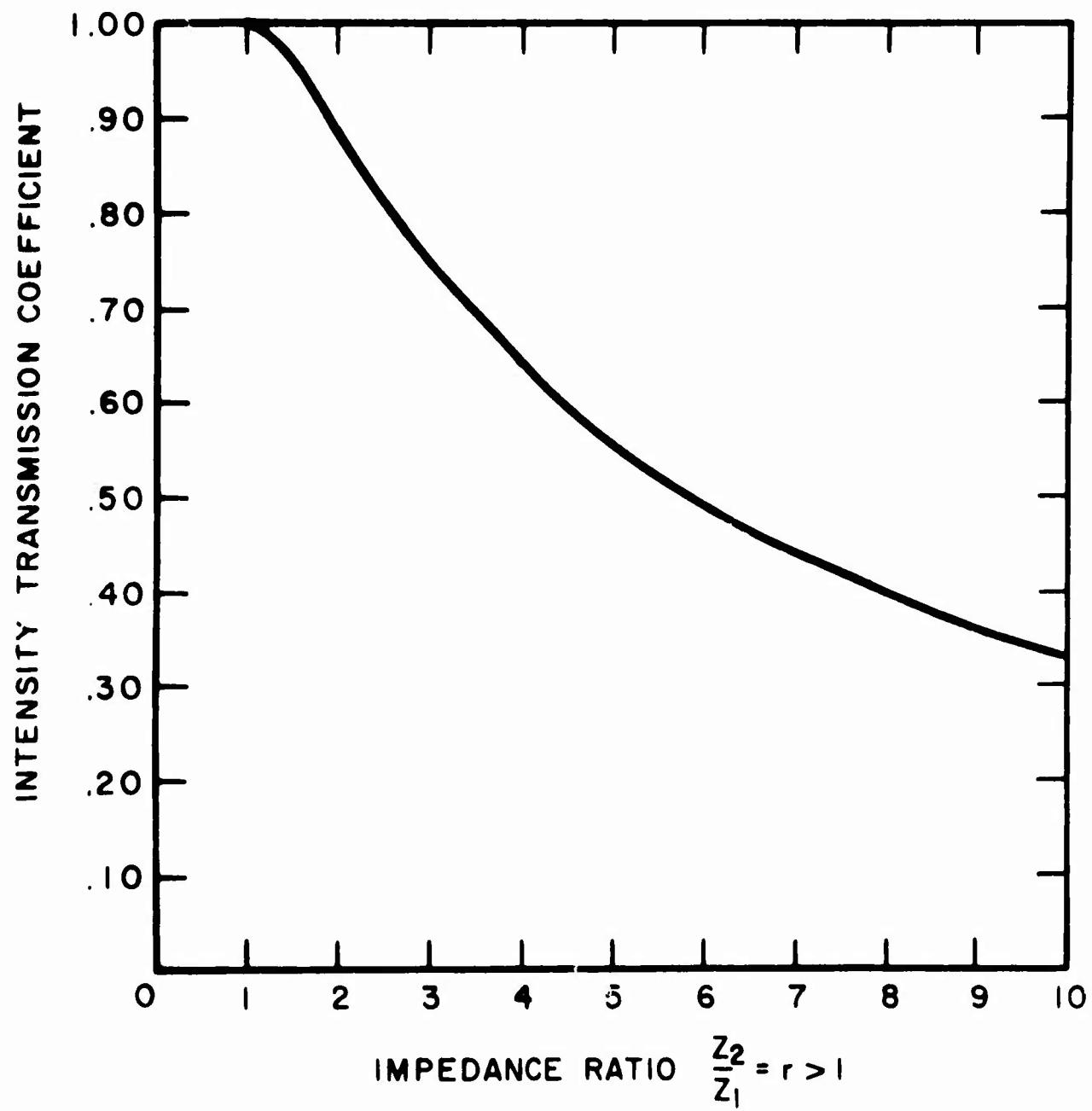
FIGURE 2.- Transmission Coefficient Curve for Impedance Ratios Greater Than One.

12

Then

$$(\alpha_{12})\ (\alpha_{23})\ =\ \alpha_{123} \tag{13}$$

where

α_{123} = Intensity transmission coefficient from unit, through pad to rock.

Optimum coupling or maximum transmission of energy from unit to rock (or vice versa) through the pad can be obtained by choosing a pad substance with an acoustic impedance, Z_2 such that the impedance ratio between the unit and the pad is the same as the impedance ratio between the pad and the rock.

$$\frac{Z_3}{Z_2}\ =\ \frac{Z_2}{Z_1}\ =\ r_{23}\ =\ r_{12} \tag{14}$$

$$Z_2\ =\ \sqrt{(Z_1)\ (Z_3)} \tag{15}$$

To prepare pads with appropriate impedances for optimum coupling in every drill hole is not practical, particularly when dealing with rocks where the impedance varies appreciably from place to place. Satisfactory results can be obtained through use of coupling pad impedance values that lie somewhere between the impedances of the rock and the transducer. Use of a pad which has the same impedance value as the rock's is similar in effect to coupling the unit directly to the rock. Pads with impedance values outside the limits indicated result in excessive reflective losses.

The acoustic impedance for lead-zirconate-titanate transducers placed on the transmitters and receivers used in this work is in the order of 5,500,000 pounds per foot^2- sec.* For comparison, Table I

---

* In general, the effect of thin diaphragms used between transducer and pad appeared negligible.

lists typical acoustic impedance values for rocks at the test sites
and for some of the substances considered for coupling use. Inspection
of the table indicates, that for the transducers used, 3,200,000 pounds
per foot ^{2} - sec. is a desirable, general value for coupling-pad
characteristic impedance and 2,500,000 is a useful minimum value.

Among substances considered for coupling pad use, cements and
epoxies of organic chemical composition usually have impedances
that are too low for general use.

High-grade plaster of paris (hydrostone) has an impedance of
1,170,000 pounds per foot ^{2} - sec., too low a value for many rocks.

Ordinary quick-setting Portland cement with common washed
sand in a one, to one, to three-fourths, parts-by-volume mixture of
cement, ordinary washed sand and water respectively, has an acoustic
impedance value of 1,500,000 pounds per foot ^{2} sec. When sized
magnetite sand (-42, +80 mesh) is used instead of ordinary sand, the
impedance is 2,000,000. A special quicksetting cement ("Atlas
Lumnite") with ordinary washed sand (one to one parts by volume
mixture) has an impedance value of 1,700,000. "Atlas Lumnite" with
sized magnetite sand (-42, +80 mesh) in a one to one parts by volume
mixture gives a material with an impedance of 2,550,000. If the
cement mixture is made to set under 250 psi pressure the impedance
increases slightly to 2,700,000 pounds per foot ^{2} sec.

In all cement mixtures discussed, approximately 1/2 part of water
by volume was used. Test specimens were 2-inch by 2-inch by 6-inch
rectangular prisms formed in wooden forms. Specimens were left
to set in the forms, under moist conditions for 24 hours. Samples were
then removed and placed under water for another 24 hours. Test
specimens which set under pressure (2-1/4-inch-diameter by 6 inches
long) were formed in 2-1/4 inch inside diameter steel tubing and kept
under pressure for 48 hours before being removed.

In addition to having proper impedance value, substances for use
as pads should (1) adhere firmly and permanently to the rock surface;
(2) be moldable and capable of yielding a smooth finished surface; (3)
be structurally strong and stable over extended periods of time.

14

The "Atlas Lumnite" and sized magnetite mixture, set under pressure fulfills all requirements satisfactorily, and was used in all set-ups at Idaho Springs and San Manuel.

TABLE I

APPROXIMATE CHARACTERISTIC ACOUSTIC IMPEDANCES

Material	Pounds per foot square second
Halite - Sylvite	
IMC Mine, Carlsbad	1,850,000
IMC Mine, Carlsbad	1,950,000
Disseminated copper porphyry	
San Manuel Mine, 2,015 Level	2,350,000
San Manuel Mine, 2,015 Level	750,000
San Manuel Mine, hand specimen	3,190,000
Granite gneiss	
Colorado School of Mines, Miami Tunnel	2,600,000
Colorado School of Mines, Miami Tunnel	2,700,000
Acrylic plastic	650,000
Hydrostone	1,150,000
Quick-setting Portland cement and sand (1 to 1 by vol.)	1,500,000
Quick-setting Portland cement and magnetite (1 to 1 by vol.)	2,000,000
"Atlas Lumnite" Cement and sand (1 to 1 by vol.)	1,700,000
"Atlas Lumnite" Cement and magnetite (1 to 1 by vol.)	2,550,000
"Atlas Lumnite" Cement and magnetite (1 to 1 by vol.) set under 250 psi	2,700,000

SECTION III

INSTRUMENTATION

General Comments

General arrangement of the equipment used for transmission of piezoelectrically produced sonic pulses through rock in place is shown schematically in figure 3. The operating cycle commences at the pulse generator with simultaneous generation of a high voltage main pulse and low voltage trigger pulse. The high-voltage pulse is led to the piezoelectric transmitter where conversion from electrical to mechanical energy takes place. The trigger pulse is led to the oscilloscope trigger circuit which starts the sweep horizontally across the screen from left to right. At the transmitter the mechanical energy in the form of a mechanical pulse passes to the rock, and as a sonic pulse, travels through to the receiver. There the mechanical energy is converted back to an electric pulse, which is amplified, and led to the oscilloscope to cause an upward (or downward) deflection of the sweep. Basically, this completes the operating cycle. The distance from the beginning of the trace to the point of deflection depends on the time taken by the sonic pulse to travel from transmitter to receiver.

A new operating cycle is started each time the generator produces a high-voltage pulse. When operating cycles are repeated regularly and often enough, the display on the oscilloscope screen will appear as a continuous rather than as an intermittent picture. The pulses are uniformly the same, which permits the steady display of pulse arrivals. If desired, the pulses can be photographed using time exposures of several seconds where necessary.

17
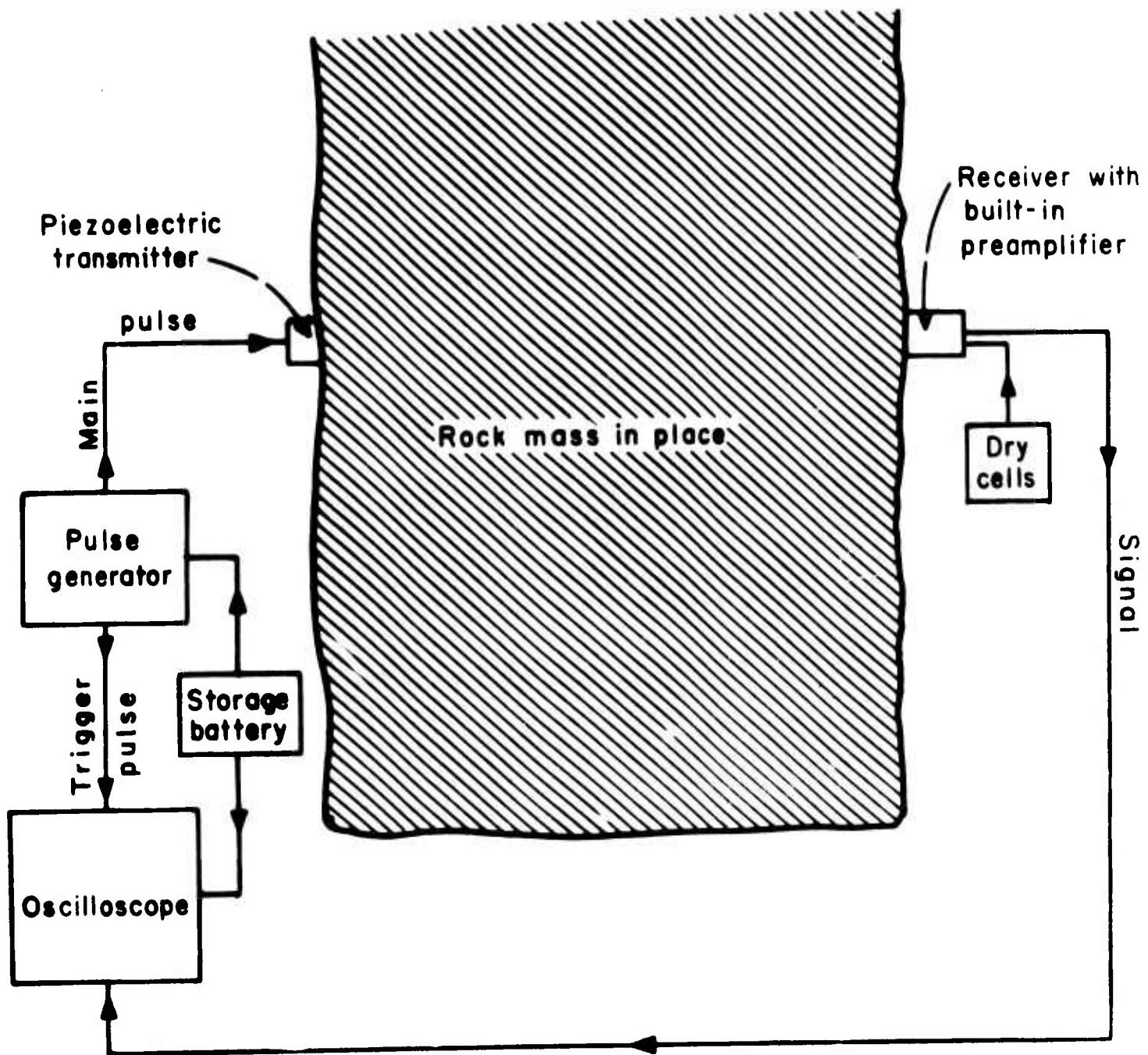
FIGURE   3.- Block Diagram of Equipment for Piezoelectric
Pulse Transmission.

18

SECTION IV

PIEZOELECTRIC COMPONENTS

General Comments

Basically the three transmitting and receiving units described by this report consist of a metal shell with internal insulating liner. This shell contains and holds a transducer against the rock or coupling pad by adjustable spring pressure. Major difference between models is the manner in which the shell is attached to the rock.

Work in piezoelectric pulse transmission done previously as described in U. S. Bureau of Mines Report of Investigations, RI ___ (Ref. 1) showed the advisability of modifying the method used for mounting transmitter and receiver to rock in situ. Models described in this report are mounted by insertion into a hole drilled in the rock, rather than by bolting onto a pad on the surface of the rock, as described in the earlier report. The first of the three models, F-II, (figure 4) is secured against the bottom of the hole by means of a nut and expanding shell system. The depth of hole required is between 13-1/2 and 14 inches. Because of the system used for securing , Model F-II transmitters and receivers can be used only in rocks which are not prone to crumble nor are seriously shattered or broken.

Model F-III (figure 5) transmitter and receiver are adaptable to holes of variable depth. A steel tube liner is inserted in the hole and secured by grouting between the outside of the liner and the drill hole walls. The unit (receiver or transmitter) slides inside the liner to the bottom of the hole and is held there by a push tube backed up by a gear-puller-like device used as spring compressor, which is hooked on two holes in the steel tube liner, near the collar of the drill hole (figure 6). This method of mounting is effective in rock material that is friable, badly fractured or shattered, as well as in sound rock.

Model F-IV transmitter and receiver (figure 7) are adaptable to holes of variable depth. As mounted on rock-salt formations, no steel liners were placed in the drill holes. Each unit was held against the bottom of the drill hole with a push tube resting against a backup plate bolted to the rock face at the drill hole collar (figure 8).
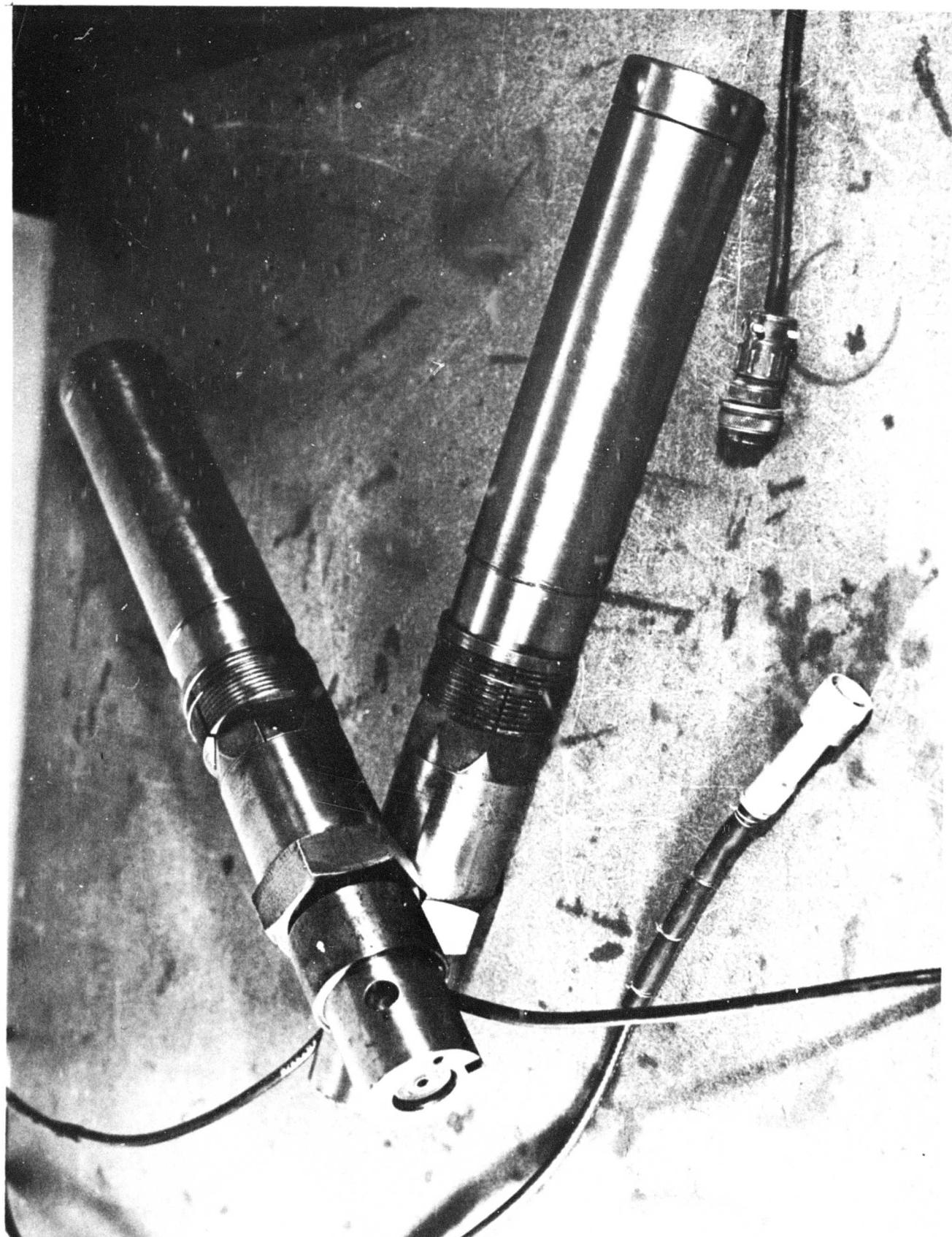
Figure 4. Model F-II Transmitter (Lower) and Receiver (Upper).
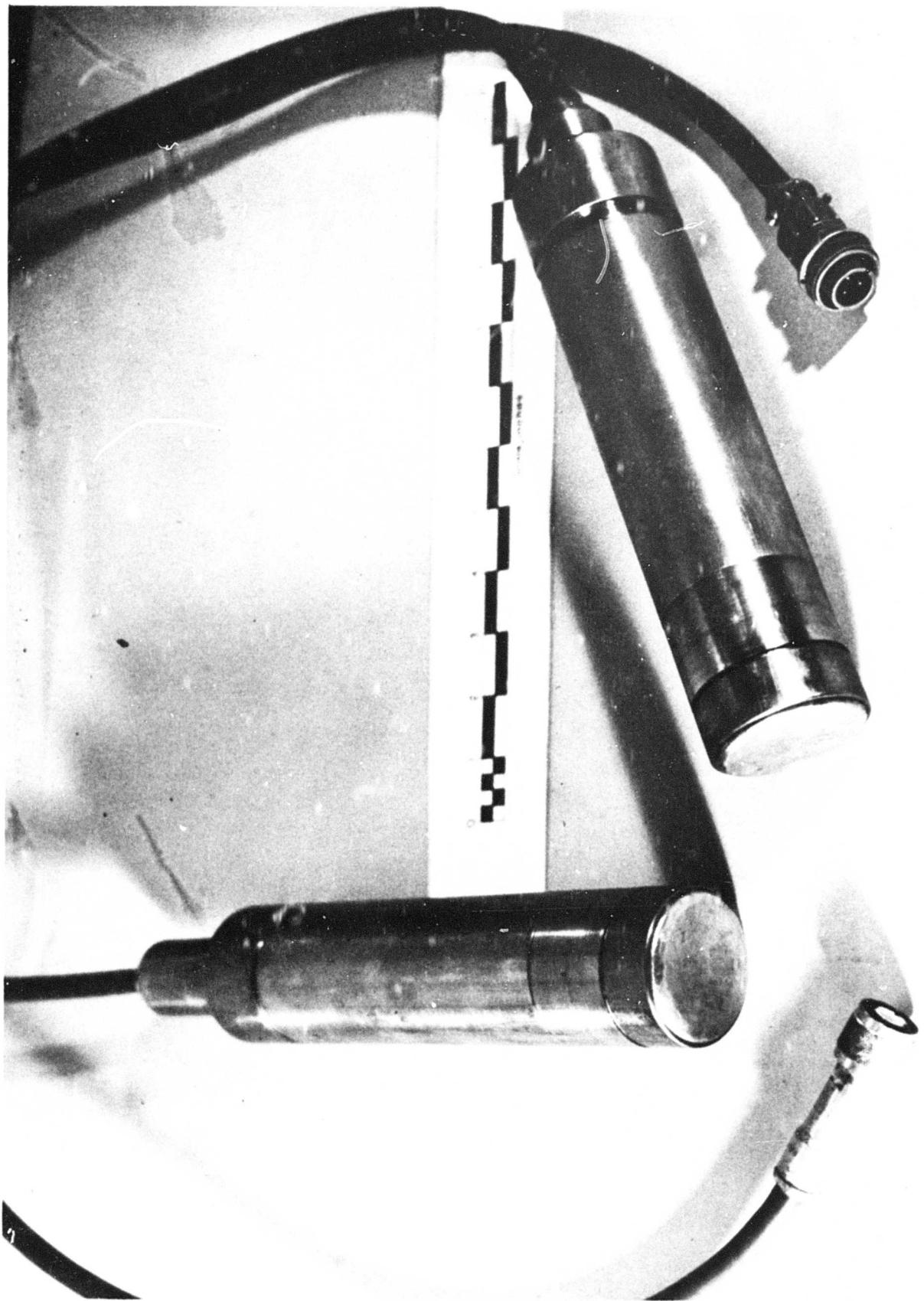
Figure 5. Model F-III Transmitter (Left) and Receiver (Right).

① Coupling grout
② Model F-Ⅲ
③ Push tube, aluminum
④ Grout, hydrostone
⑤ Liner, seamless steel tubing

⑥ Coupling, aluminum
⑦ Wedge, wood
⑧ Cable
⑨ Puller

Scale, inches
0 1 2 3 4
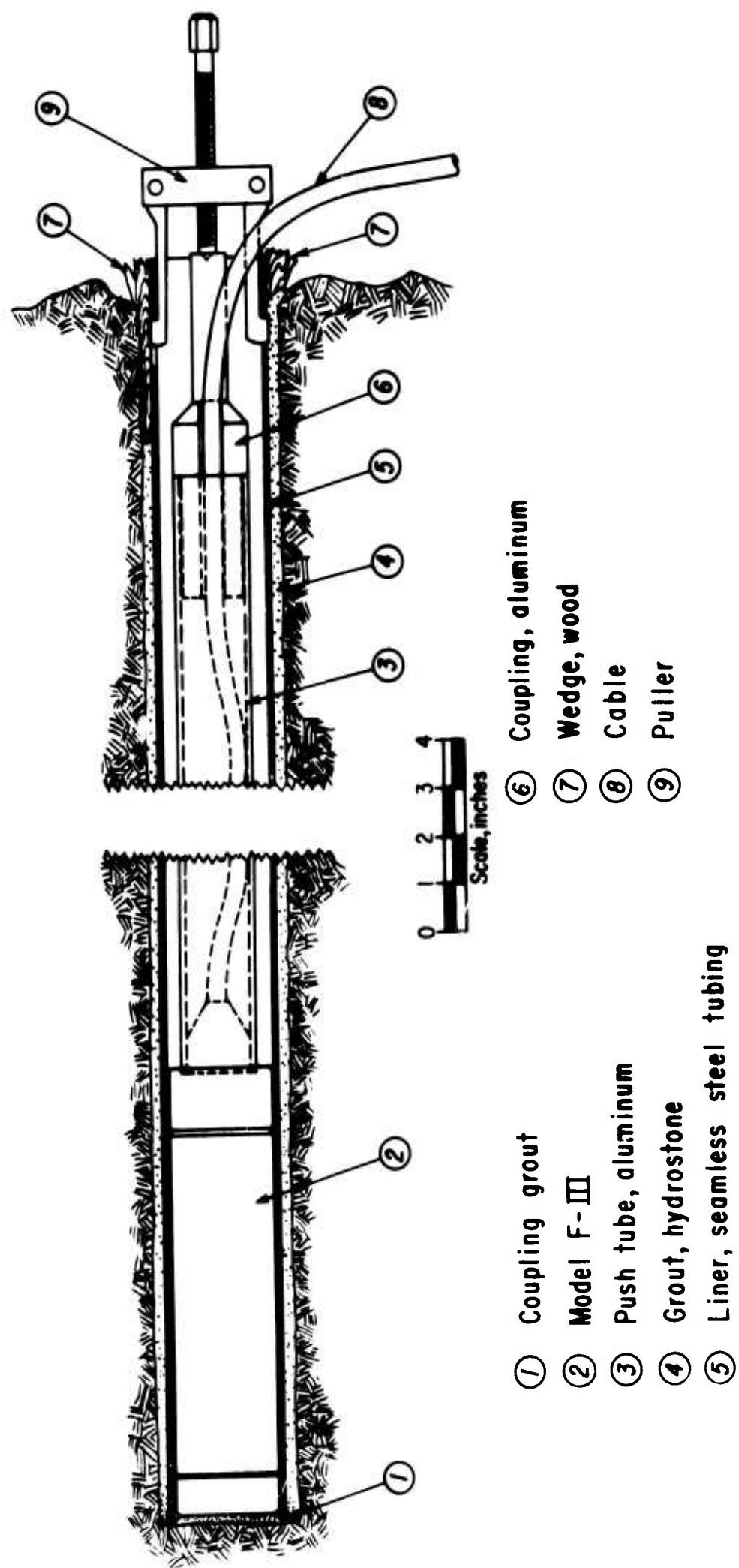
FIGURE 6.-Section Through Drill Hole Showing Model F-Ⅲ Transmitter or Receiver Mounted Against Rock.

22
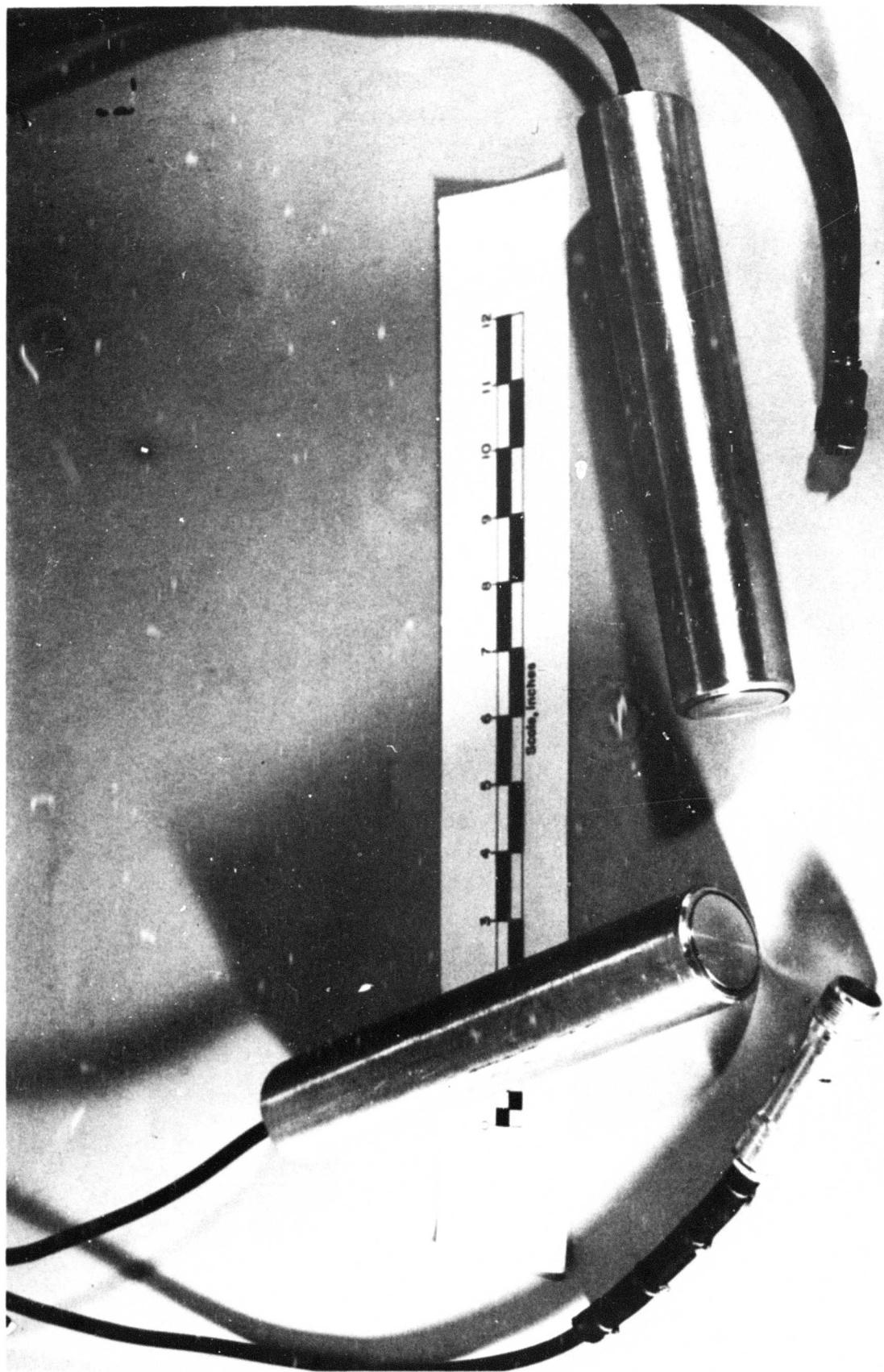
Figure 7. Model F-IV Transmitter (Left) and Receiver (Right).

23

Legend:

1. Model F-IV
2. Standard lag bolt threads
3. ⅝" Stud, steel
4. Standard machine threads
5. Back-up plate, steel
6. Cable
7. Push tube, aluminum

Scale, inches
0 1 2 3 4
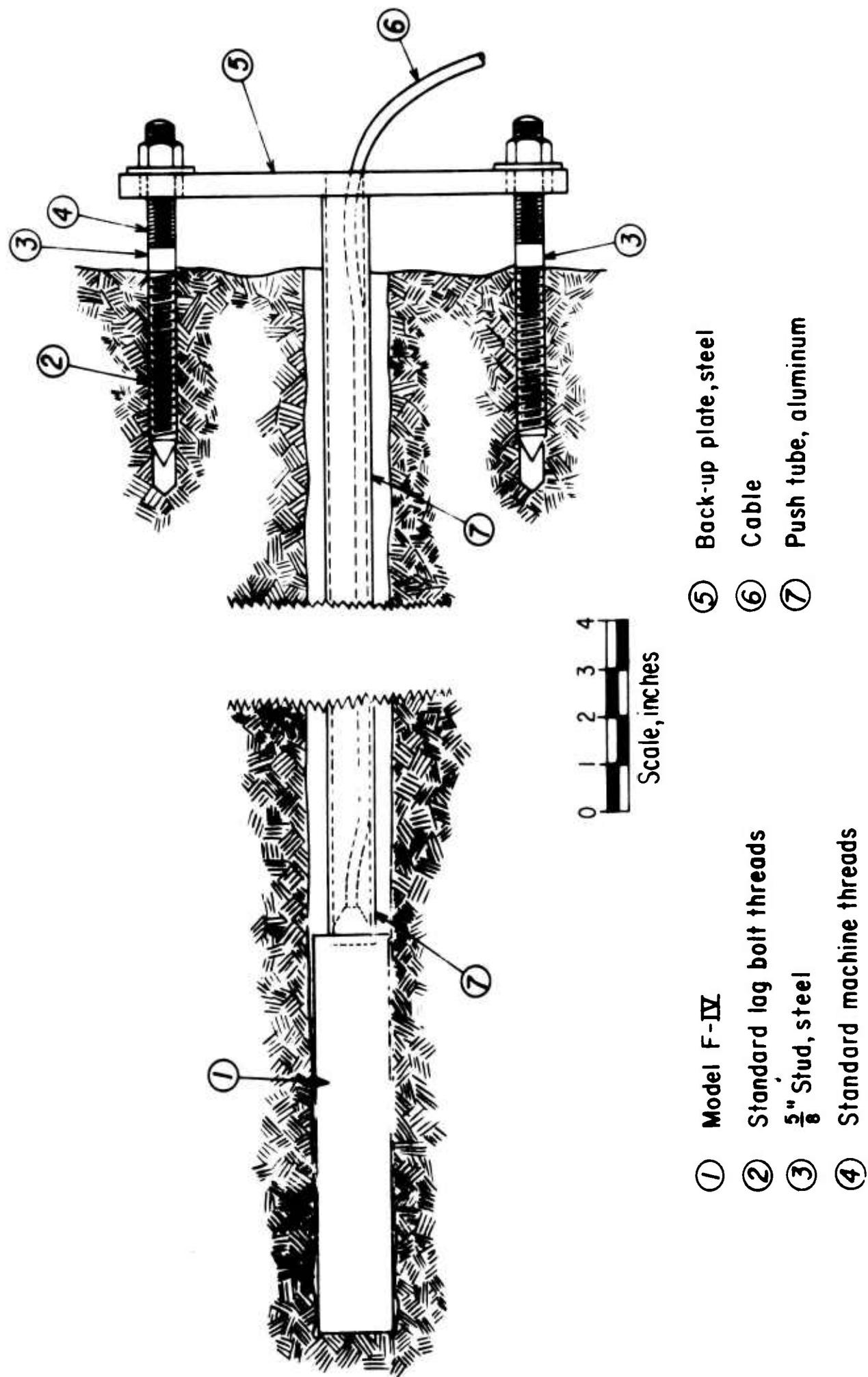
FIGURE 8.-Section Through Drill Hole Showing Model F-IV Transmitter or Receiver Mounted Against Rocksalt.

24

Models F-III and F-IV are generally superior to F-II because of flexibility in the manner of mounting, simplicity of design, and lightness.

Model F-II Transmitter and Receiver

Model F-II transmitter (figure 4) and receiver (figures 4 and 9) are different as follows. In the transmitter, part 5, figure 9, is solid rather than hollow, and is connected to the central lead of a coaxial cable. The coaxial cable shield is grounded to the body of the transmitter as is done with the receiver. In all other respects transmitter and receiver are the same. Each complete unit weighs 30 pounds.

The transducers used were discs 2 inches in diameter, 1/2-inch thick. The purpose of the articulated mass is to permit adjustment of diaphragm and transducer to small misalignments which the coupling pad surface may have with respect to the axis of the hole. If the transducer is not aligned properly when compressed against the pad surface, stress concentrations may develop in the transducer which could result in poor operation and occasional transducer fracture. Maximum spring load on the transducer is approximately 3,500 pounds (1,110 psi). The spring can be compressed and regulated with a hydraulic rig that attaches to the unit or preferably, with a simple gear-puller device. The spring may be locked with a pin in the maximum load position, if so desired.

Mounting of Model F-II to Rock Mass

A 2-3/4- to 3-inch diameter hole (preferably 2-3/4 inch) was drilled 14 inches straight into the rock. Percussion drills with "X" type bits were used in hard rock. Ordinary cross bits were unsatisfactory because of the tendency to "rifle" the drill hole wall in some rocks. Rotary drills with sawtooth bits were used in salt. Diamond drills with suitable bits could be used to drill the holes wherever feasible.

In rocks other than salt, drill hole and face should be thoroughly cleaned and washed with water. If air is used for blowing out, care must be taken not to spray oil (from hose line oilers) into the hole. The cleaned bottom of the hole was covered with enough cement coupling

grout (mixed as described previously under "Coupling of Transmitter and Receiver to Rock") to produce a pad approximately 1-1/4-inch thick. The pad was formed by forcing the grout against the bottom of the hole with a transmitting or receiving unit, or with a dummy made for this purpose until the grout had set.

In rock salt the coupling face was produced by cutting the bottom of the drill hole to a machine smooth surface with a specially made carbide insert bit.

In mounting Model F-II units to a finished hole, the first step was to clean thoroughly the coupling surface of the hole, and the unit's diaphragm. A light coat of ordinary machine lubricating oil was smeared on the diaphragm and the unit was inserted in the hole, pressed against the face, and the pressure nut (figure 9, part 22) was tightened with a box wrench until the expansion shells (figure 9, part 19) had gripped securely the walls of the drill hole. Spring pressure was then applied to compress the transducer against the coupling pad (Part VI, Procedure).

Model F-III Transmitter and Receiver

Assembly drawings of transmitter and receiver are shown in figure 10. Each unit weighs approximately 9 pounds. The transmitter transducer measures 1-3/4-inch in diameter by 1/2-inch in thickness; receiver transducer measures 1.9 inches in diameter by 1/2-inch in thickness. Articulated masses backing up the transducers (figure 10, parts 11 and 27) are simpler in construction but more limited in movement than with Model F-II. This simplification was made possible because with Model F-III, the units slide into a smooth-walled steel tube (instead of into a drill hole), and because the coupling pad surface can be finished consistently very nearly at right angles to the longitudinal axis of the steel tube (see the following section titled "Mounting of Model F-III to Rock Mass").

The springs (figure 10, part 17) that serve to compress the transducers are very stiff which allows a load of up to 4,000 pounds to be applied, if necessary, with relatively few turns of the spring compresser or puller device. Springs are acted on by a plunger assembly (figure 10, part 4) which is pressed by a push tube (figure 6, part 3), which is

26

1. Braided ground lead to cable shield
2. Preamplifier output and battery leads
3. Shielded two lead cable
4. Preamplifier chamber
5. Preamplifier case assembly, brass
6. Transducer
7. Diaphragm, stainless steel
8. Diaphragm holding ring, alloy steel
9. Articulated mass assembly, stainless steel

10. Front body-shell
11. Spring seat, nylon insulator
12. Spring seat
13. Insulating shell, acrylic plastic
14. Pressure spring, alloy steel
15. Spring compressing piston
16. Lock Washer, copper
17. Body coupling
18. Holding snap ring
19. Four piece expansion shell, alloy steel

20. Four piece wedge, alloy steel
21. Rear body-shell
22. Pressure nut, alloy steel
23. Thread guard

Scale, inches

FIGURE 9.-Assembly Drawing of Model F-II Receiver

27

1. Two lead shielded cable
2. Preamplifier output and battery cable
3. Back collar, stainless steel
4. Plunger assembly, stainless steel
5. Preamplifier case, brass
6. Preamplifier chamber
7. Diaphragm mounting ring, alloy steel
8. Reinforcing ring, alloy steel
9. Diaphragm, stainless steel
10. Transducer
11. Transducer backing assembly
12. Disc, brass
13. Insulating washer, mylar
14. Body, stainless steel
15. Insulating liner, acrylic plastic
16. Centering collar, rubber
17. Spring, alloy steel
18. Cable shield and ground
19. Cable holding wedge, stainless steel
20. "O" ring seal, rubber
21. Conductive wiremesh ring
22. "O" ring snubber, rubber
23. Coaxial cable
24. Spacer, stainless steel
25. Washer stack, brass and polyethylene alternately
26. Insulator, nylon
27. Damping mass, stainless steel
28. Centering ring, rubber
29. Inner insulating liner, acrylic

RECEIVER

TRANSMITTER

Scale, inches

FIGURE 10.-Assembly Drawing of Model F-III Units

28

acted upon by a coupling (figure 6, part 6) which in turn takes the load applied by the spring compressor (figure 6, part 9), which is anchored or hooked onto the steel tube (figure 6, part 5) grouted to the rock. The lead cable (figure 6, part 8) is brought out of the push tube through a slot in the coupling (figure 6, part 6).

Mounting of Model F-III to Rock Mass

Straight holes, 3 inches in diameter, drilled in rock to the desired depth are required for mounting units. In the work described by this report most holes were drilled to a 42-inch depth. The balance were taken to 72 inches. Percussion drills with "X" type bits were used in hard rock, for reasons described under Model F-II. Seamless steel tubing 2-3/4 inches outside diameter with 0.120 inch wall thickness was used for making drill hole liners. Clearance between liner and an inserted unit was 0.060-inch. Tighter clearance could result in jamming of the unit if dirt should accidentally find its way into the tube. Liners were cut squarely to lengths of 42 or 72 inches depending on drill hole depth. Drill-hole bottom-end of each liner had notches 1/8-inch deep cut around the edge to allow passage of coupling grout. Two opposed 1-inch-diameter holes (figure 11, part 4) were located in each liner 1-1/2-inches from the collar end, for hooking the puller legs (figure 11, part 5).

Procedure for grouting a liner into a drill hole is as follows (figure 11):

1. Clean and wash out drill hole to remove dirt. If oil is present, use a suitable solvent.

2. Insert pad-forming piston-assembly into liner with forming face towards notched end of liner to a position approximately at the middle of the liner.

3. With liner-notched-end up, pour into liner a high-grade plaster of paris(hydrostone, etc.) and water mixture which should be sufficiently thin to remain fluid for not less than five minutes.

Scale, inches

1. Piston, pad-forming face, stainless steel
2. Tube, aluminum
3. Centralizing guide, aluminum
4. Hole 1" diameter
5. Puller
6. Coupling, aluminum
7. Coupling-grout, pad-forming-piston assembly
8. Grout, hydrostone
9. Piston seal, formed hard rubber
10. Coupling grout
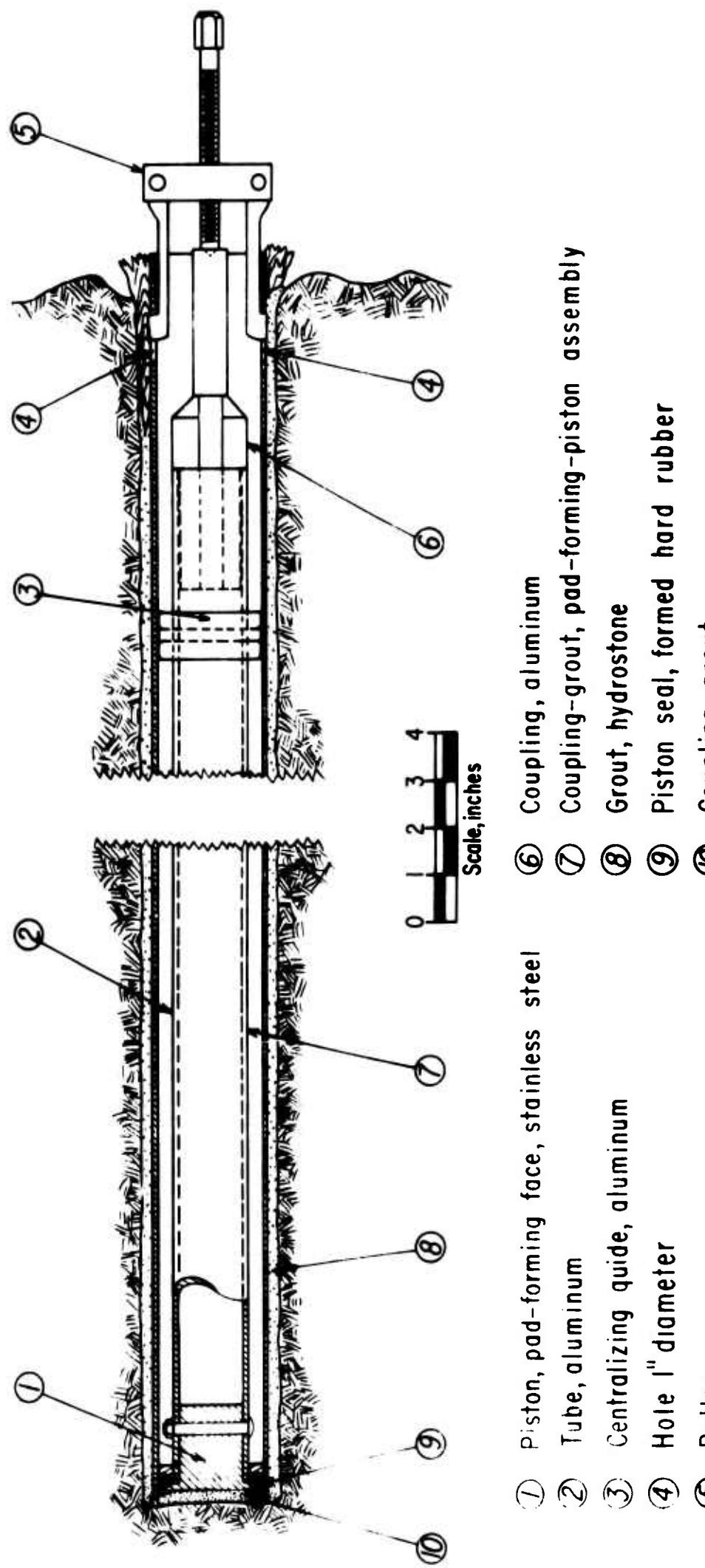
FIGURE 11.–Section Through Drill Hole, Showing Coupling Grout Pad being Formed by Pad-Forming-Piston Assembly

4. Quickly place liner into the hole notched end first and seat against the hole bottom.

5. Drive two to four narrow wooden wedges between collar of hole and liner to hold the liner seated against the bottom of the hole while the next step is performed.

6. Push piston all the way in against the bottom of the hole, which will squeeze the grout through notches to fill the space between liner and drill hole. Excess grout will run out of the hole collar.

7. Allow the grout to harden.

8. Pull out the piston assembly with a long hook.

9. Wash the grout from the hole bottom and remove excess water. Keep rock surface free of grease and oil.

10. Prepare special coupling grout and place in the liner an amount that will form into a 1/4-inch-thick pad.

11. Push the coupling grout against the bottom of the drill hole with a clean piston assembly, place coupling (part 6) and attach puller as shown in figure 11.

12. Tighten puller with a small wrench.

13. Leave pressure on until coupling grout has set properly.

14. Remove puller, coupling and piston assembly. The setup is now ready to take a Model F-III unit.

The pistons used for setting coupling grout have a shallow notch cut just deeply enough into the hard rubber piston seal to allow the air to escape as the piston pushes the coupling grout toward the face of the hole.

The pistons used for forcing grout around the liner should not have notched piston seals.

31

Model F-IV Transmitter and Receiver

This model was specially designed for use in 1-3/4 inch diameter holes drilled in halite-sylvite rock formations. Assembly drawings of transmitter and receiver are shown in figure 12. Each unit weighs approximately 3 pounds. The transducers used measured 1/2-inch in thickness by 1-inch in diameter, although 1-1/8-inch diameter ceramics may be utilized.

A stiff, machined aluminum alloy (2017) plate (figure 12, part 4) was used in place of a flexible diaphragm. This feature does away with the need for articulated damping masses (figure 12, parts 6, 8 and 18).

Springs are similar to their counterpart in Model F-III, but lighter. Springs are acted on by a plunger assembly (figure 12, part 1) which is pressed upon by a push tube (figure 8, part 7) which takes the load applied by a heavy steel back-up plate bolted down to the wall rock with two steel studs, nuts and washers, as shown in figure 8, parts 3 and 5. Pressure adjustment was made by tightening the stud nuts. The lead cable was brought out of the push tube through a suitably lined up hole in the back-up plate. Electrical connectors on the leads were sufficiently small to slip through the push tube and back-up plate hole.

Mounting of Model F-IV to Rock Mass

A straight hole 1-3/4 inches in diameter was drilled in halite-sylvite rock to a depth determined by the purpose of the test to be made. (Drill hole depths used in this work were 14 or 18 inches in machine cut mine openings, and up to 9 feet in old pillars.) Holes were drilled with ordinary tungsten carbide insert wing bits mounted on auger type rotary drills. Bottom of the hole was finished flat and smooth by replacing the wing bit with a specially made finishing bit. This bit has four tungsten carbide inserts set crosswise on the bit face, and machine-ground to produce a true flat surface when used against the bottom of the hole. This procedure was possible because of the rock formation.

After the drill hole was finished, locations for the stud holes (figure 8) were spotted with the back-up plate centered over the main
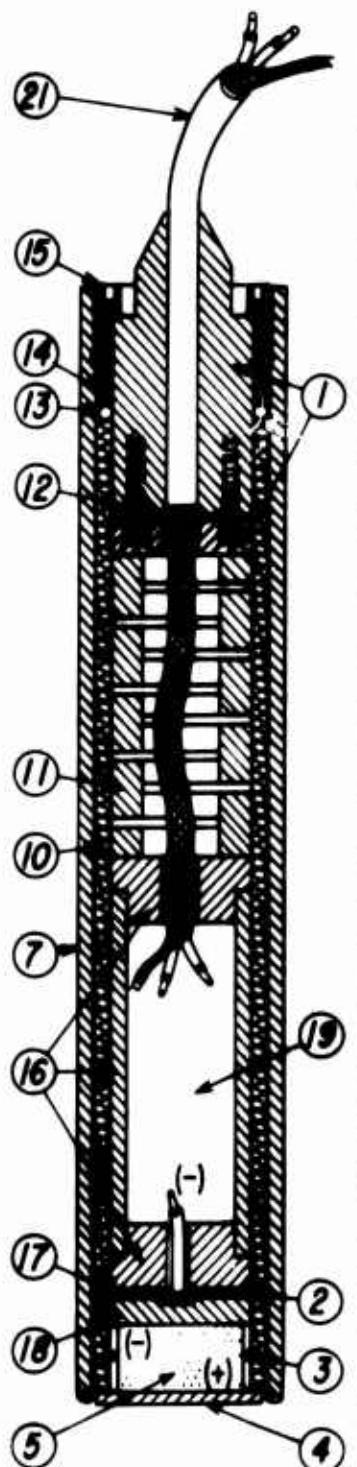
①	Plunger assembly, stainless steel
②	Disc, brass
③	Centering ring, rubber
④	Diaphragm, aluminum (2017)
⑤	Transducer
⑥	Spacer, stainless steel
⑦	Body, aluminum
⑧	Damping mass, stainless steel
⑨	Insulator, nylon
⑩	Insulating liner, acrylic plastic
⑪	Spring, alloy steel
⑫	Cable shield and ground
⑬	"O" Ring seal, rubber
⑭	Conductive wire mesh ring
⑮	Back collar, stainless steel
⑯	Preamplifier case assembly, brass
⑰	Insulating washer, mylar
⑱	Spacer, brass
⑲	Preamplifier chamber
⑳	Coaxial cable
㉑	Two lead shielded cable

RECEIVER

TRANSMITTER

Scale, inches
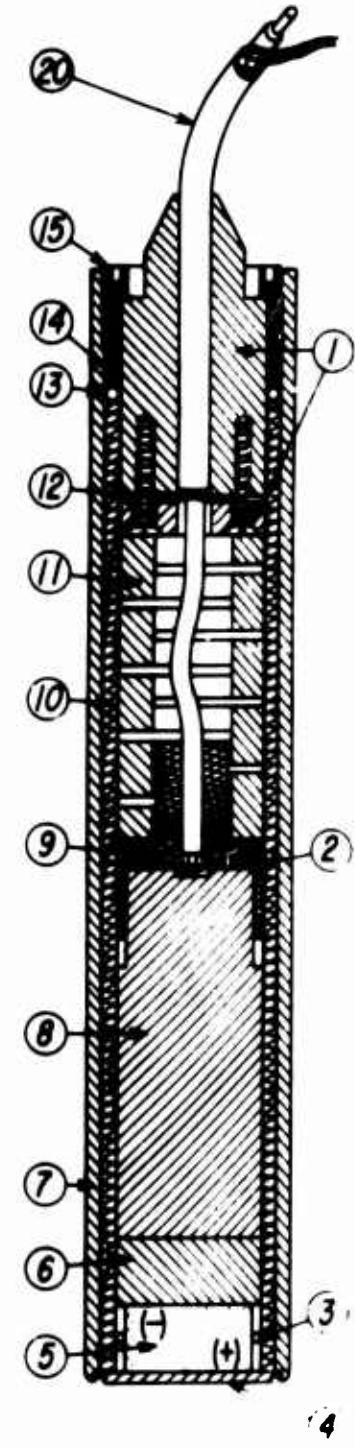
FIGURE 12.-Assembly Drawing of Model-IV Units.

33

drill hole as guide. Stud holes were then drilled in the rock with an ordinary 1/2- or 9/16-inch twist drill. Studs with 5/8-inch lag-bolt threads were then screwed into the holes.* The main hole was thoroughly cleaned of dust, and a Model IV unit with a coat of ordinary machine oil on the diaphragm plate was inserted in the hole and pushed against the face with a push tube of the proper length. The back-up plate was bolted down and tightened, as necessary, against the push tube to hold the tube and unit in place. This completed the mounting operation.

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*The technique of screwing lag bolts or studs into holes drilled in salt is generally used by the mine operators for holding and supporting equipment and service lines.

SECTION V

ELECTRONIC COMPONENTS

General Comments

Portability of equipmen t in confined spaces is an important aspect
of this work. Ability to deliver maximum energy to the rock at the
point of input is another. Sensitivity to detect arrival of low level
acoustic energy in rock is yet another requirement.

Portability in confined spaces limits equipment to man-carried,
compact, self-powered units.

Acoustic energy traveling in many rocks dissipates rapidly, a
condition which requires that a high level of acoustic energy must be
introduced, if a detectable amount of acoustic energy is to be picked
up at considerable distance from the point of input. A continuously
maintained input of energy at high intensity levels requires a suitable
source of power, which is not available in small, portable batteries.
Additionally, electronic equipment that can handle high power con-
tinuously requires heavy components capable of dissipating heat as
well.

Solution of the problem lies in applying very high intensity levels
of energy to the rock for a very short period of time (less than one
millisecond) followed by a comparatively long period of inactivity (in
the order of 100 milliseconds) before a new application of energy is
commenced. The average energy consumed in this manner is low, con-
sequently heat dissipation problems are negligible which permits use
of light electronic components in general.

The type of wave form or pulse shape delivered by a pulse generator
determines the complexity of the circuitry. Pure sine waves and well
defined rectangular waves or pulses require considerable circuitry (and
therefore bulk) to produce, particularly at high-intensity levels. The
circuits developed, and described in this report are relatively simple,
and are basically similar. Model III pulse generator produces an
asymmetric pulse which has a steeply rising slope which levels off for
a short distance and is followed by a relatively gently drooping slope

(figure 13). Model IV generator pulse has a sinusoidal-like shape
the leading edge of which rises steeply to a peak followed by a more
gently descending curve (figure 14).

Sensitivity of reception is limited by signal to noise ratio between
amplitude of signal received to amplitude of spurious noise (which
includes sonic, external radio frequency and internal electronic).
Some noise is caused by normal mine activity, and cannot be con-
trolled too well. External radio frequency and power line hum can be
dealt with by proper shielding. Internal electronic noise depends on
circuit design and nature of components particularly from the sonic
receiver to the first preamplification stage. To minimize electronic
noise in general, preamplifiers for all three models were built into
the receivers and placed as close as possible to the receiving trans-
ducers (figures 9, 10, and 11, parts 4, 6 and 19 respectively). Major
aim of preamplifier design was maximum sensitivity to weak signals
with maximum amplification in a minimum of space.

Because the pulses transmitted and signals received are repetitive
and extremely stable, a portable oscilloscope is used for visual display
and analysis of the signal received. For permanent records (where
parallax error is not serious) photographs may be taken of the oscillo-
scope screen.

Pulse Generator Model III

The Model III pulse generator (figure 15) is a lightweight (12.5
pound) portable unit that draws less than 10 watts from an external
12-volt battery. When used with a PZT-5 transducer 2-1/2-inch
diameter, 1/2-inch-thick, the main pulse has a peak amplitude of 10,000
volts. The pulse (figure 13) has a rise time * of 5 microseconds and a
fall time of 40 microseconds. Pulse width is 38 microseconds. Nominal
pulse repetition rate is 10 pulses per second. Synchronized with the

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* Rise time is the interval required for the leading edge of the wave
form to rise from 10- to 90-percent of the peak value. Fall time is
the interval required for the trailing edge to fall from 90- to 10-percent
of the peak value. The pulse width is the interval between 50 percent
on the leading edge of the wave form to 50 percent on the trailing edge
of the wave form.
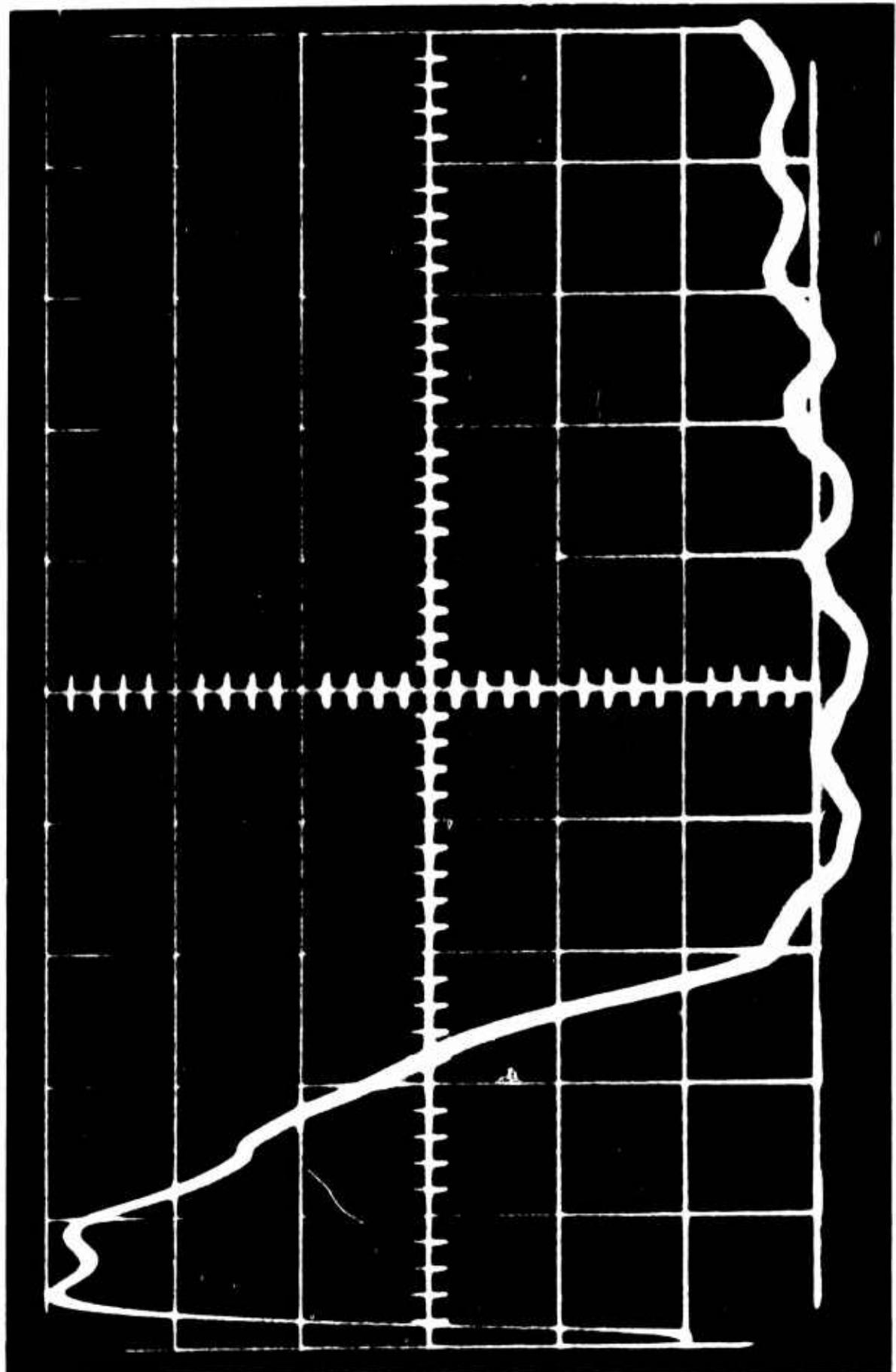
Figure 13. Output Pulse, Pulse Generator Model III.

37
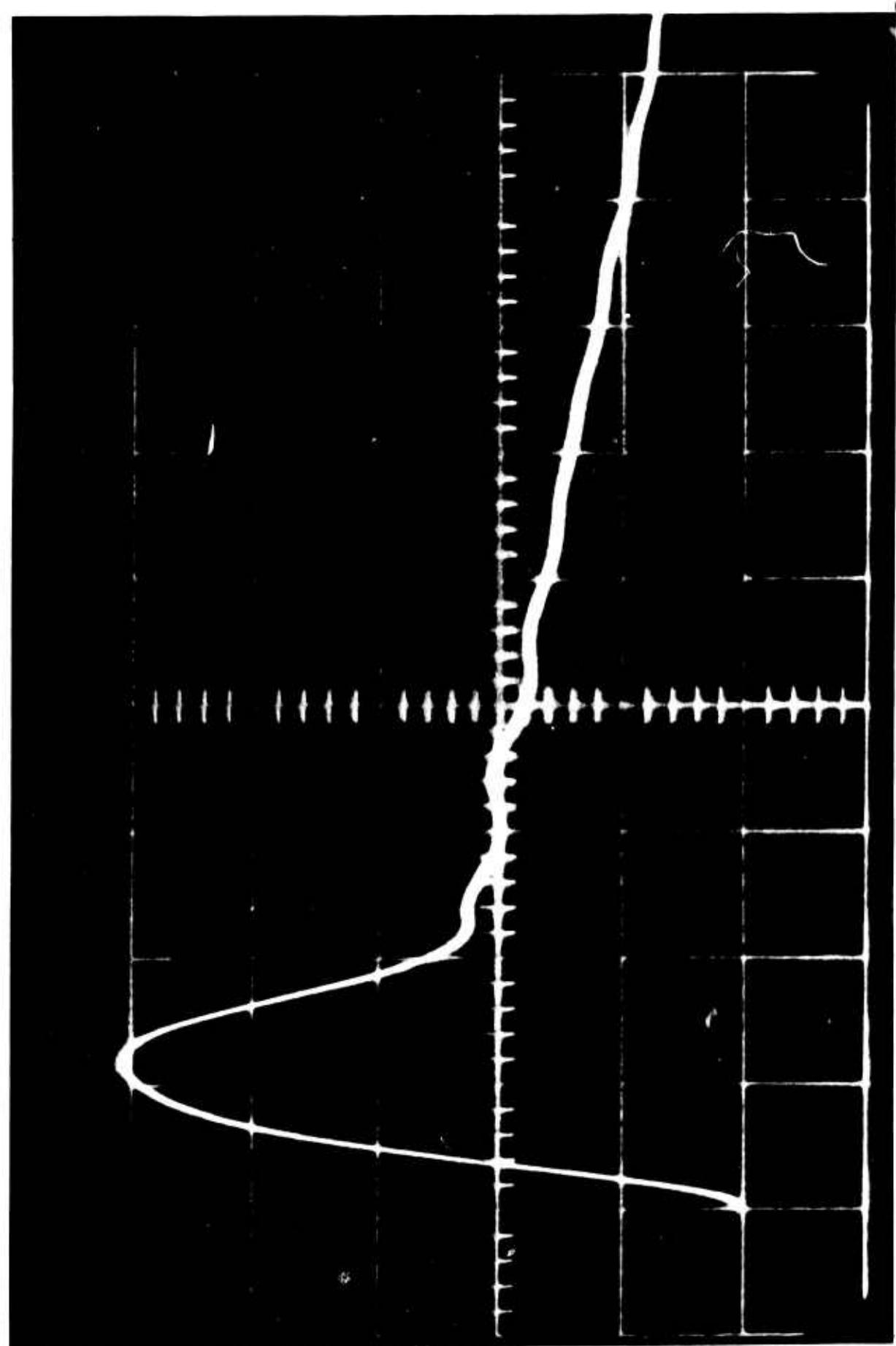
Figure 14. Output Pulse, Pulse Generator Model IV.

38
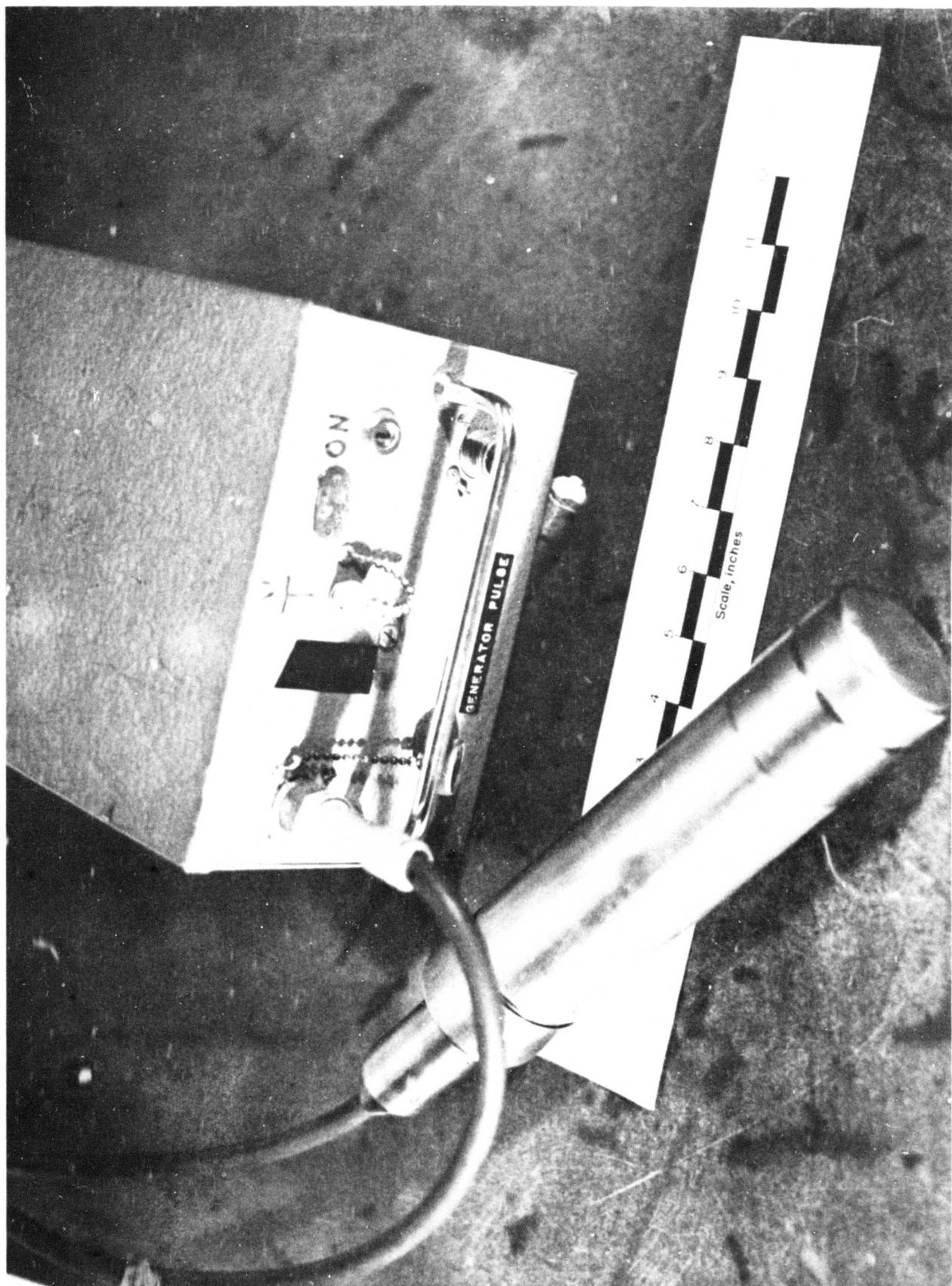
Figure 15. Pulse Generator Model III with F-III Transmitter Plugged In.

39

main pulse is a trigger pulse, (amplitude 25 volts and rise time 0.03 microsecond) which is used for triggering an oscilloscope at a distance of over one mile with RG62/U coaxial cable.

The pulse generator (figure 16) consists of four sections: The high-voltage power supply, the trigger multivibrator, the high voltage switching circuit, and the syncronized trigger pulse circuit.

The high voltage power supply provides in the order of 500 volts DC to the high voltage switching circuit through resistor R_{11}. High voltage is produced by step-up transformer T_1 as follows. Transistor Q_4 which is normally in the conducting state, allows current to flow into the primary transformer T_1 to create a magnetic field in the transformer core. Transistor Q_4 is periodically and abruptly switched off and on, which causes the magnetic field in the core to collapse and build up. The collapsing magnetic field produces a high voltage spike at the secondary of T_1 which is rectified by diode D_2, filtered by capacitor C_3 and results in high voltage DC output. Transistors Q_1 and Q_2 form an oscillator circuit which produces a 1 kilocycle rectangular wave that is amplified by Q_3. The positive peaks of the amplified wave switch Q_4 off while the negative peaks turn Q_4 on. Transistor Q_5 and diode D_1 regulate the voltage on the primary of transformer T_1 to keep it constant despite variations in the 12-volt storage battery supply. Resistor R_7 controls the high-voltage-power-supply output voltage, which in turn controls the pulse generator output to the transducer. Resistor R_7 is set to give 10,000 volts across the transducer.

The trigger multivibrator supplies the timing pulses to the high-voltage switching circuit. Transistors Q_6 and Q_7 produce a rectangular wave which is shaped by capacitor C_9 and choke L_1 into positive and negative spikes. Transistor Q_8 amplifies and inverts the negative spikes which are applied to the gate of the silicon-controlled rectifier, (SCR) in the high-voltage switching circuit.

In the high voltage switching circuit capacitors C_6 and C_7 along with L_2 comprise a pulse forming network (PFN). This network is charged by the high-voltage power supply through resistor R_{11}. The PFN is then discharged through the pulse transformer T_2 by the SCR. The high current discharged from the PFN into the pulse transformer T_2 causes

40
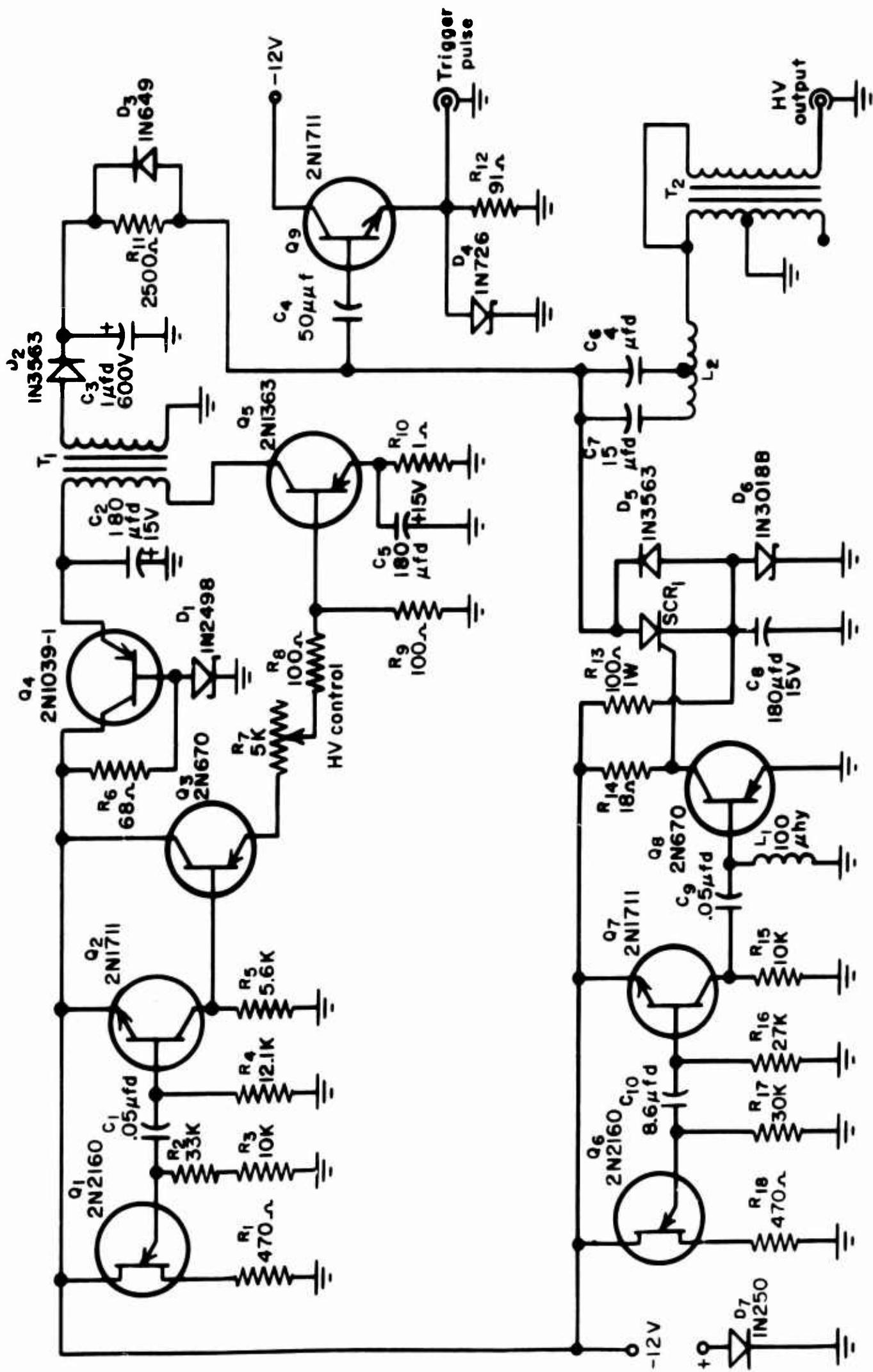
FIGURE 16. - Schematic Diagram of Pulse Generator Model II

41

a very high voltage to be produced at the secondary of the transformer. After each pulse the capacitors in the PFN are recharged by the power supply. Diodes D_3 and D_5 aid in the recharging of the capacitors in the PFN. The gate of the SCR is negatively biased with respect to the cathode by diode D_6 , capacitor C_8 and resistor R_{13}, which permits the usual SCR voltage ratings to be exceeded.

Pulse Generator Model IV

The Model IV pulse generator is a small (15-pound) high peak-power output unit that can operate in 90-degree-F temperatures at 90 percent relative humidity. When the generator applies a 10,000-volt pulse to a "PZT-5" transducer 1/2-inch-thick and 2 inches in diameter the pulse has a rise time of 13 microseconds, fall time of 180 micro-seconds and pulse width of 24 microseconds. Under these conditions the pulse generator consumes 10 watts from a 12-volt battery to produce 16,000 watt peak-output pulses. The generator has both variable output voltage and variable repetition rate and is capable of delivering 20,000 volts if used with a sufficiently thick transducer of proper diameter. A syncronized trigger pulse is provided for triggering an oscilloscope at a distance of over one mile with RG62/U coaxial cable.

The pulse generator (figure 18) is divided into four parts: The trigger generator, the high voltage power supply, the high-voltage pulse circuit, and the synchronized trigger pulse circuit.

The trigger generator initiates the pulse sequence. Transistors Q_1 and Q_2 are connected in a relaxation oscillator circuit which generates a rectangular wave whose frequency is determined by the front panel RATE control (figure 17), resistor R_2(figure 18). Repetition rate is variable from 1.4 to 7.8 pulses per second. The rectangular waves are amplified by $Q_3$and shaped by capacitor C_3 and inductor L_1 into short positive and negative pulses. Transistor Q_4amplifies only the negative pulses which appear as positive spikes after going through transformers T_1 and T_2 .

The high voltage power supply is adjustable between zero and 600 volts by adjusting the input voltage to the supply. Between zero and 11.5 volts may be applied to the supply by the front panel VOLTAGE

42

Figure 17. Pulse Generator Model IV with F-III Transmitter Plugged In.
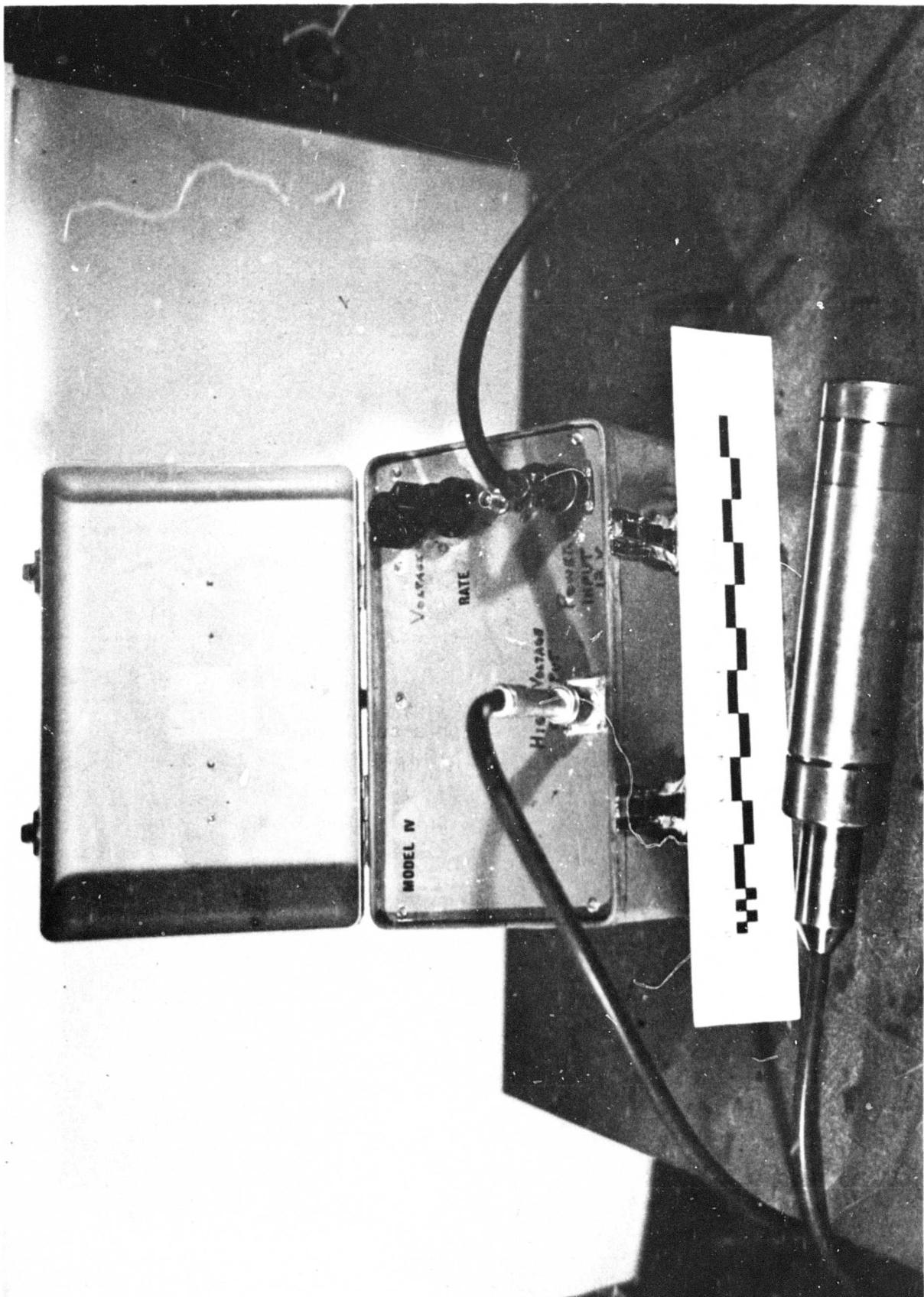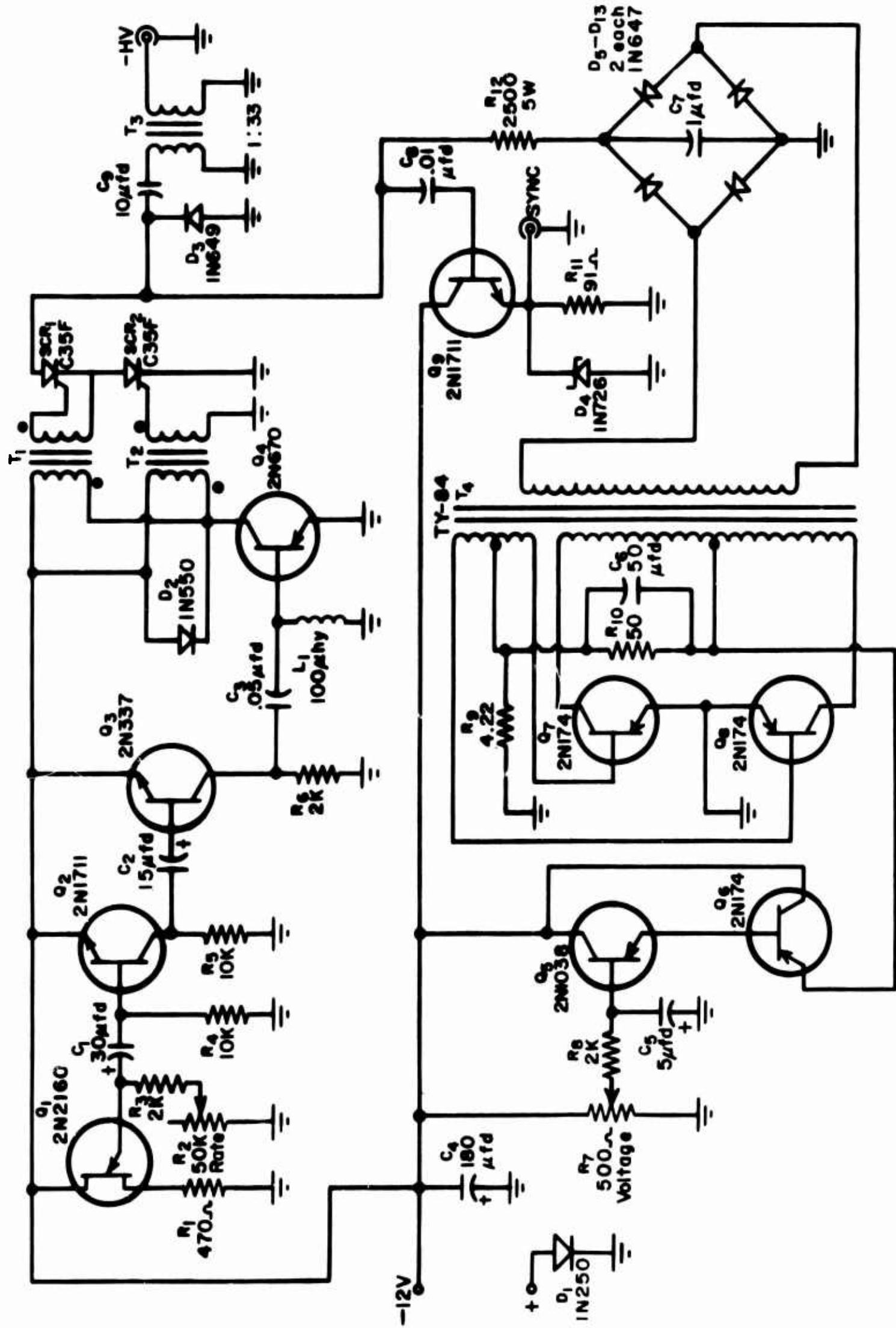
FIGURE 18.- Schematic Diagram of Pulse Generator Model IV.

control (figure 17), R_7 (figure 18) in combination with Q_5 and Q_6 (compound connected DC amplifier). Diode D_1 is a safety feature which protects the pulse generator in case the power leads are reversed. The high voltage DC power supply feeds the high voltage switching circuit through R_{12}. Basically, the supply is a self-excited stepup transformer. Transistors Q_7 and Q_8 oscillate to provide AC to the primary of T_4. The high voltage on the secondary is rectified by the full wave diode bridge D_5-D_{13}, and filtered by C_7. Each leg of the bridge has two diodes in series to withstand the high voltage.

The high voltage switching circuit produces the main pulses by stepping up the voltage from the high voltage power supply. The switching element in the circuit consists of two silicon controlled rectifiers (SCR_1 and SCR_2) connected in series. The series circuit arrangement allows twice the permissible voltage for each SCR to be applied to the circuit. The SCR's are triggered on at the same time by the spikes on the output of T_1 and T_2. As soon as the SCR's switch on, C_9 discharges through the transformer T_3. After each pulse, the SCR's turn off and C_9 recharges through R_{12}. The function of diode D_3 is to aid recharging of C_9.

The synchronized trigger pulse circuit driven by capacitor C_8 is identical to that of Model III pulse generator.

In the construction of Model IV pulse generator, the use of subassemblies facilitates maintenance and repair. There are four sections that may be disassembled but left wired together for ease of service. Heaviest part of the pulse generator, transformer T_3, is handbuilt since no suitable commercial unit was available. Special care was taken in the design and assembly of the transformer because of high voltages produced. Connecting leads on T_3 were made short because long leads would degrade overall performance. Silicone rubber was used for potting to seal against moisture and for insulation from the case.

Five percent tolerance resistors and unselected transistors were used in the generator. No failure of components has been encountered since all components are conservatively rated.

Preamplifiers

Special high gain, low-noise preamplifiers are used to amplify the weak signals from the receiving transducers. Three pre-amplifier models were built for use in each of the three transducer probes. All three models used have the same basic circuit with minor variations. All of the preamplifiers were built inside the transducer cases to shorten the cable connecting the transducer to the preamplifiers.

The basic preamplifier circuit (figure 19) has three common emitter stages arranged in cascade for maximum gain. Bulk of the amplification is provided by the second and third stages with the first stage designed to give minimum noise. The amount of internal noise generated by the first stage determines the threshhold sensitivity of the preamplifier.

Between 5 and 22 kilocycles the gain of the preamplifier is in the order of 70,000 for an input of less than 2 microvolts.* The weakest signal that can be detected in this range is less than 1 microvolt. At 2 kilocycles the gain is down to 40,000. The design emphasizes maximum sensitivity to weak signals and no special effort was made to obtain linear frequency response.

The batteries that supply power to the preamplifier are housed in a box that connects to the cable from the probe. Because the current drain is under 6 milliamperes, mercury batteries (TR146) last approximately 60 hours.

For acoustic transmissions over 500 feet an emitter-follower circuit placed in the battery box was used to lower the output impedance of the preamplifier. The emitter follower does not change the gain or frequency response characteristics of the preamplifier.

Care must be taken to ensure that physical contact is maintained between the diaphragm, the transducer, and the transducer backing assembly in all receiving units. If this condition is not met, the open-

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*Preamp uses transistors selected for low noise and high gain. Use of random units will result in lower gain and increased internal noise.
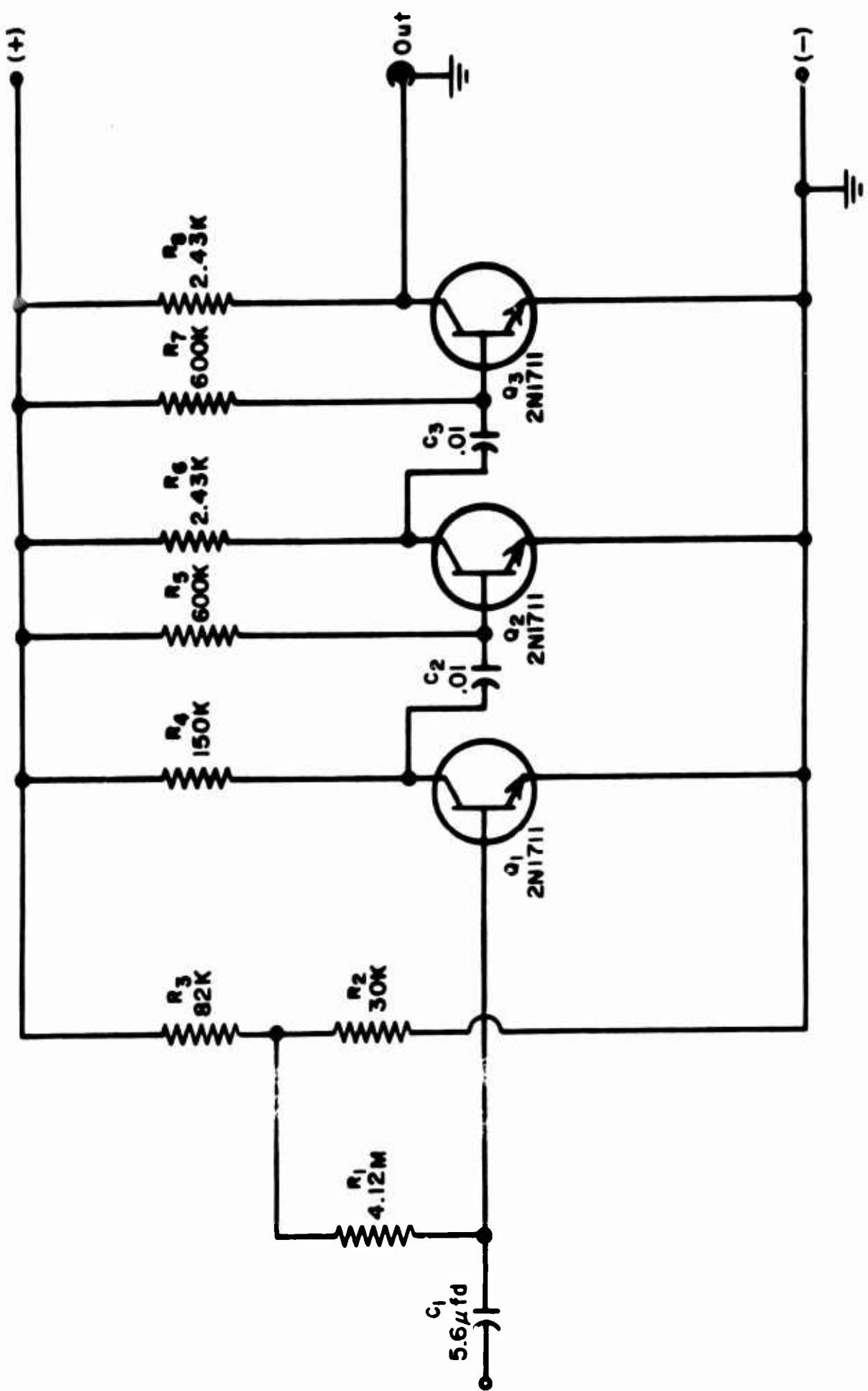
FIGURE 19.- Schematic Diagram of Preamplifier.

47

circuited transducer may inadvertently build up a sufficiently high voltage which will burn out the first stage transistor Q_1 when the open circuit is closed.

Oscilloscopes

Light, portable, moisture-resistant, battery-operated units, preferably transistorized, are required for field use in this work. Horizontal calibrated sweep rates should be in the order of 1 microsecond to 1 second per division. The vertical amplifier should have a frequency range from DC to 5 MC, and a calibrated sensitivity from 10 millivolts to 10 volts per division. External triggering must be available.

SECTION VI

PROCEDURE

General Comments

General procedure consisted of testing various rock types and striving for maximum transmission range. Model F-II units were tested first, with Model III pulse generator, in all three rock types. Subsequently, Model F-III units were tried at Idaho Springs and San Manuel with Model III and IV pulse generators. Model F-IV units were used in Carlsbad and Idaho Springs with Model IV pulse generator.

Basic parameter measured in each test was the time of the sonic pulses traveling through rock from transmitting to receiving station. Accuracy of survey measurements for distances between acoustic stations is in the order of 5 per 1,000. Accuracy of oscilloscopes used is $\pm$ 3 percent. Reproducibility of travel time readings is within 1 percent for average good conditions. Absolute accuracy of oscilloscope time reading is improved through use of a small transistorized time-mark-generator (TMG).*

Acoustic station arrays used in each mine are shown in figures 20, 21, 22, 23, 24 and 25. Stations were located to provide various ranges, and various transmitter orientations.

Procedure for taking a test reading is as follows: Transmitter and receiver units are mounted at selected stations. ring pressure on each unit is initially adjusted with the puller set e turn tighter than finger tight. Electrical equipment is connecte shown in figure 3. After a suitable oscilloscope warmup period, the pulse generator is switched on. The transmitting transducer will click audibly, pulsing against the wall rock. Intensity level and repetition rate of pulses is fixed when Model III pulse generator is used, but both are adjustable (within their ranges) as desired when Model IV is used. The oscilloscope should be set to trigger externally from the pulse generator, and a suitable horizontal sweep rate is selected. The signal which appears on

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*Quartz - crystal - oscillator, frequency - standard
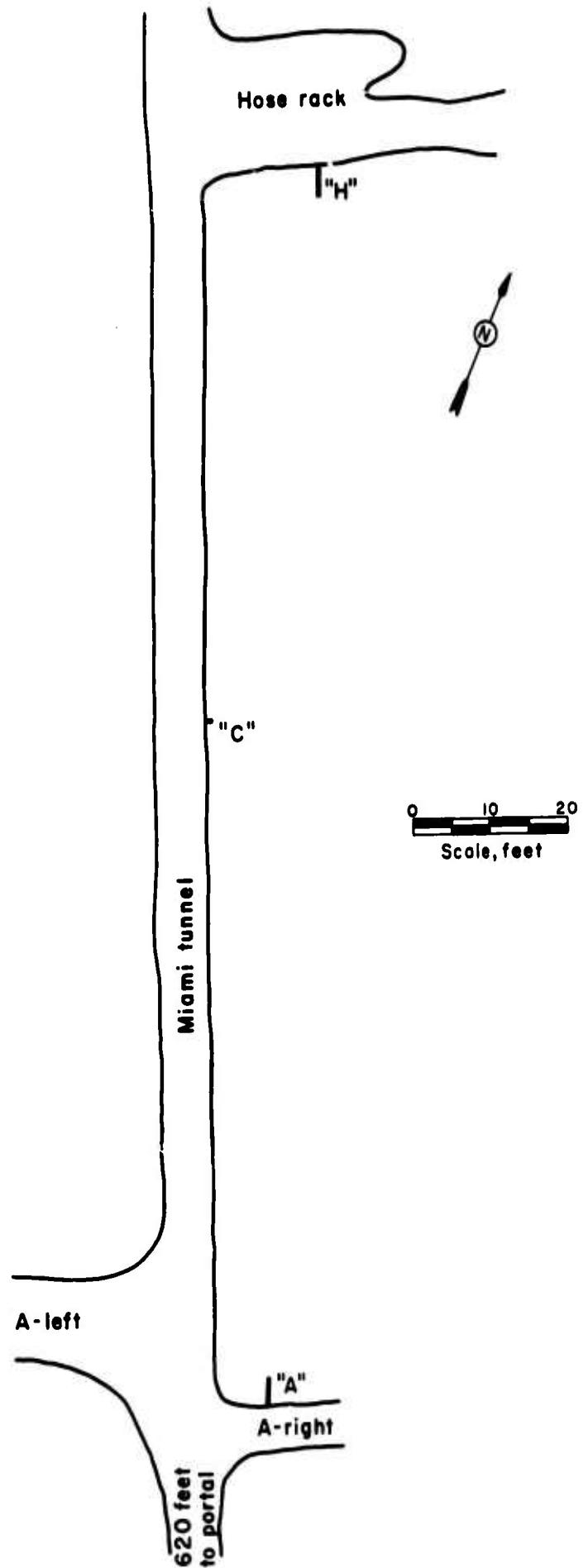
FIGURE 20.- Colorado School of Mines Experimental Mine
In Situ Test Site.
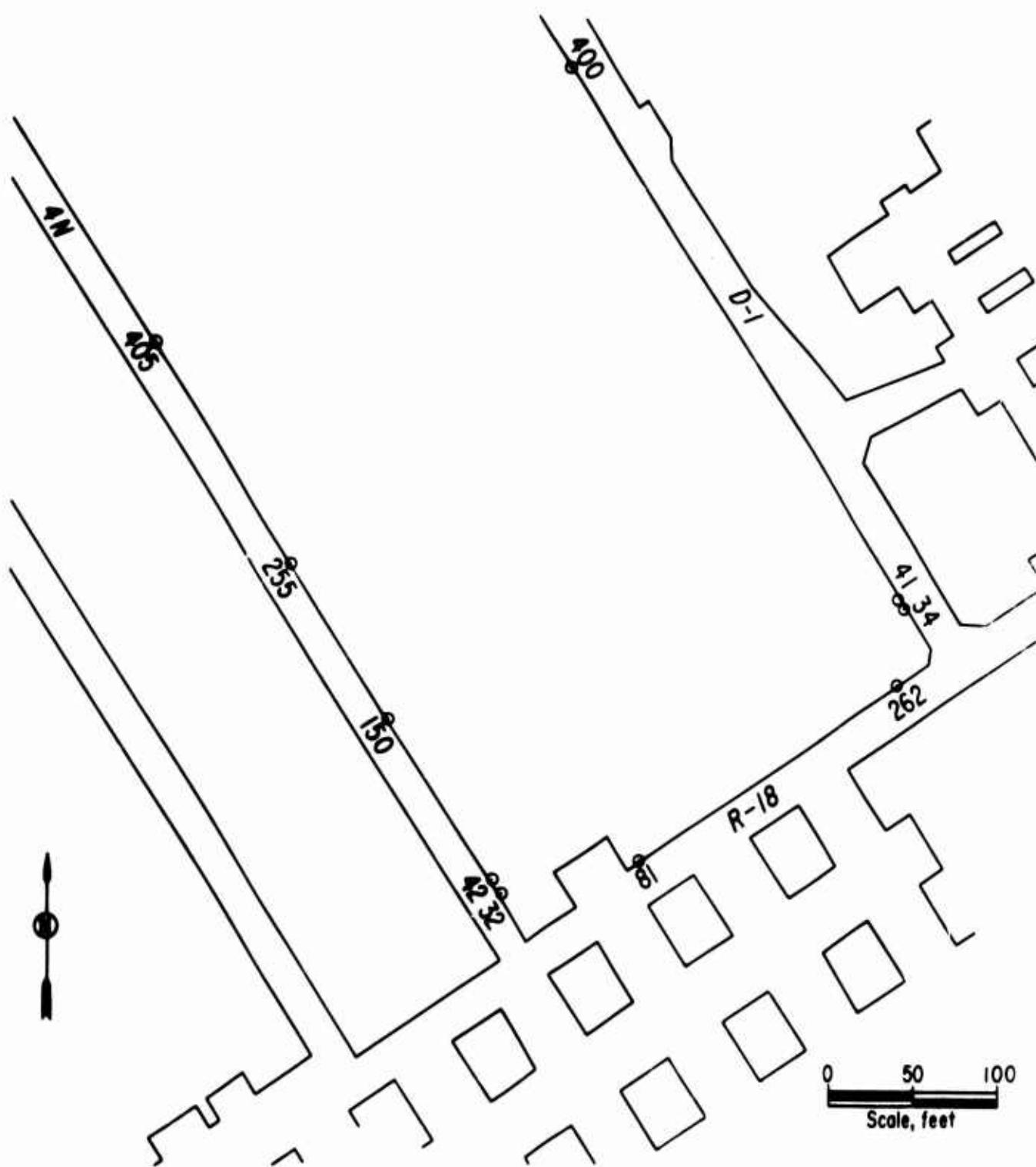
FIGURE 21.-Layout of Sonic Stations, Longwall Area, 900 Level, IMC Mine

51
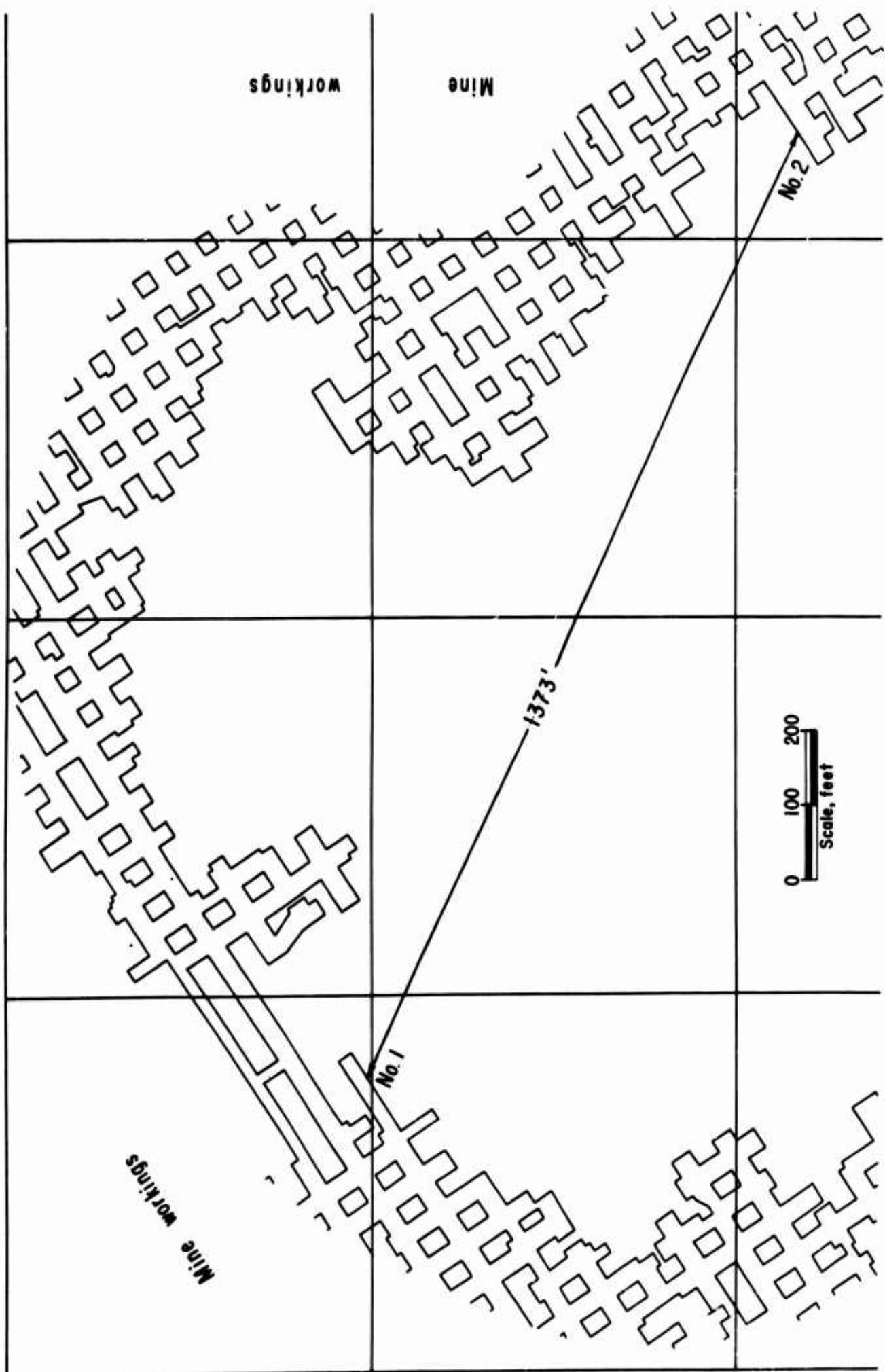
FIGURE 22.—Layout of Long Range Transmission at 900 Level, IMC Mine.

52
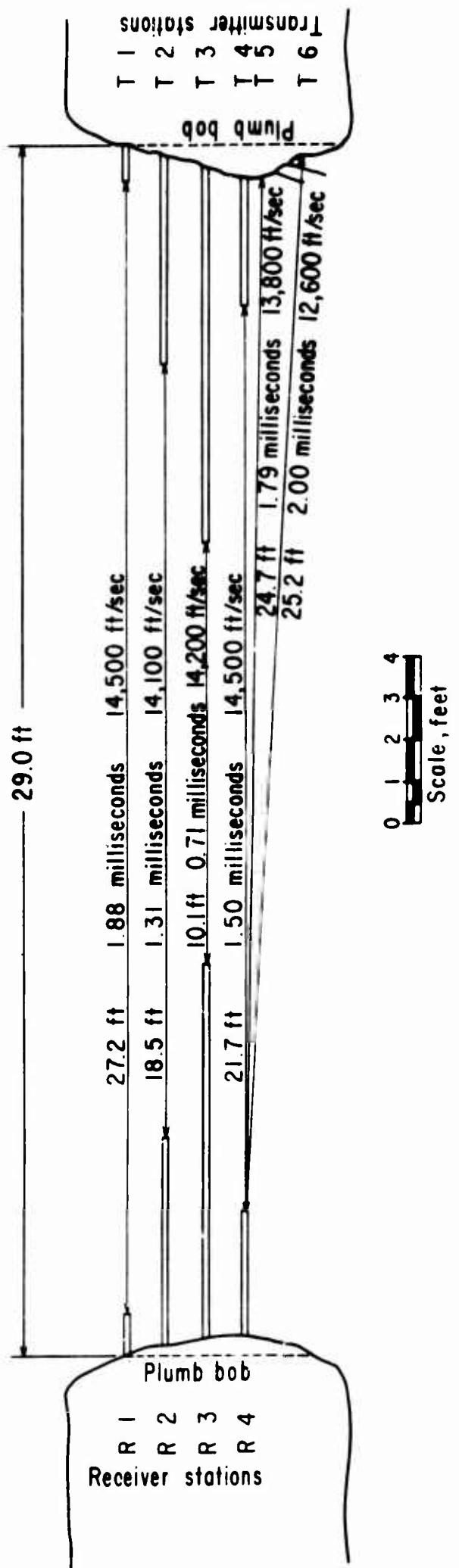
FIGURE 23.-Vertical Section Showing Sonic Stations in Pillar, 900 Level IMC Mine.

53
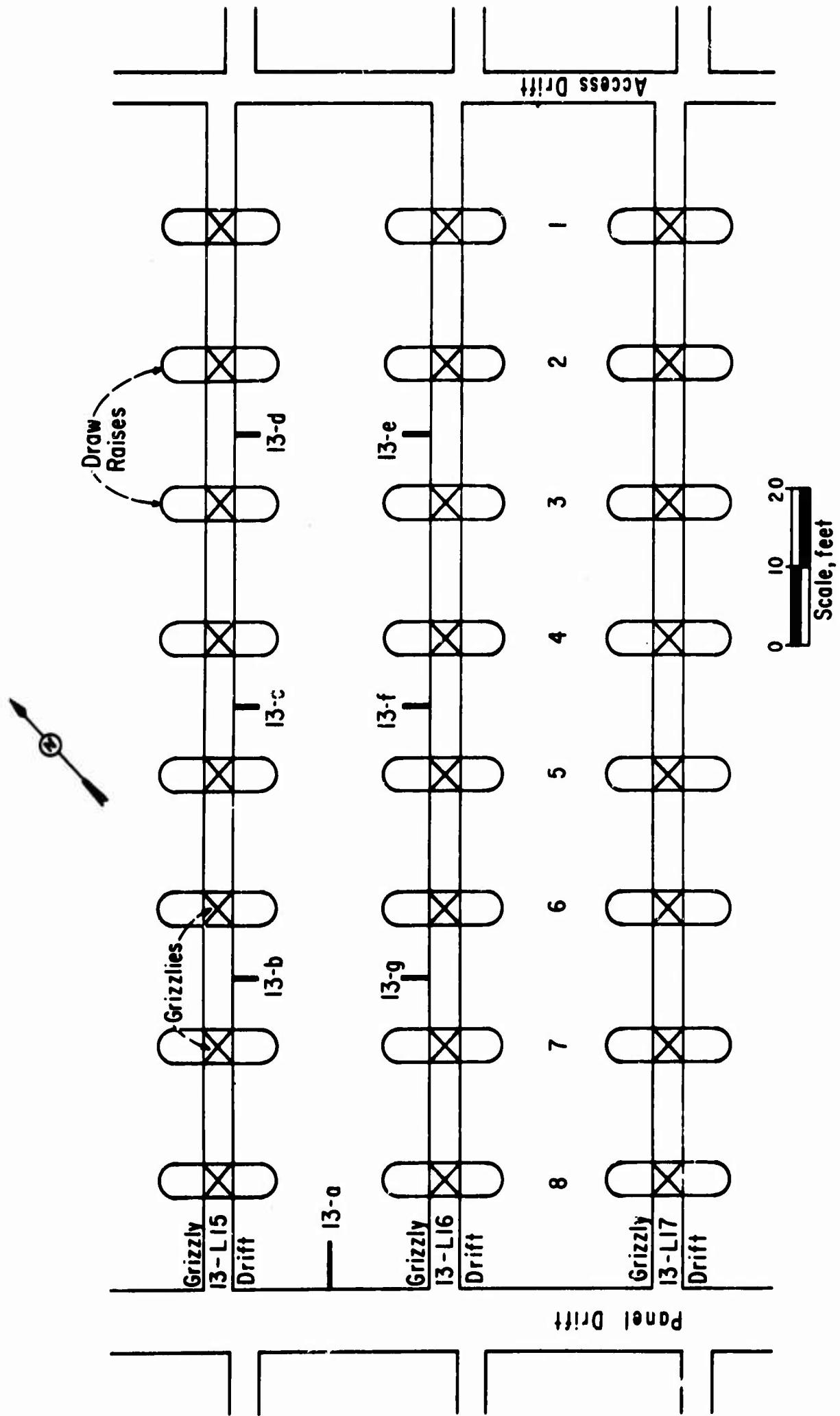
FIGURE 24.-Schematic Plan of a Portion of Panel 13, 2015 Level, San Manuel Mine Showing Locations of Sonic Stations.
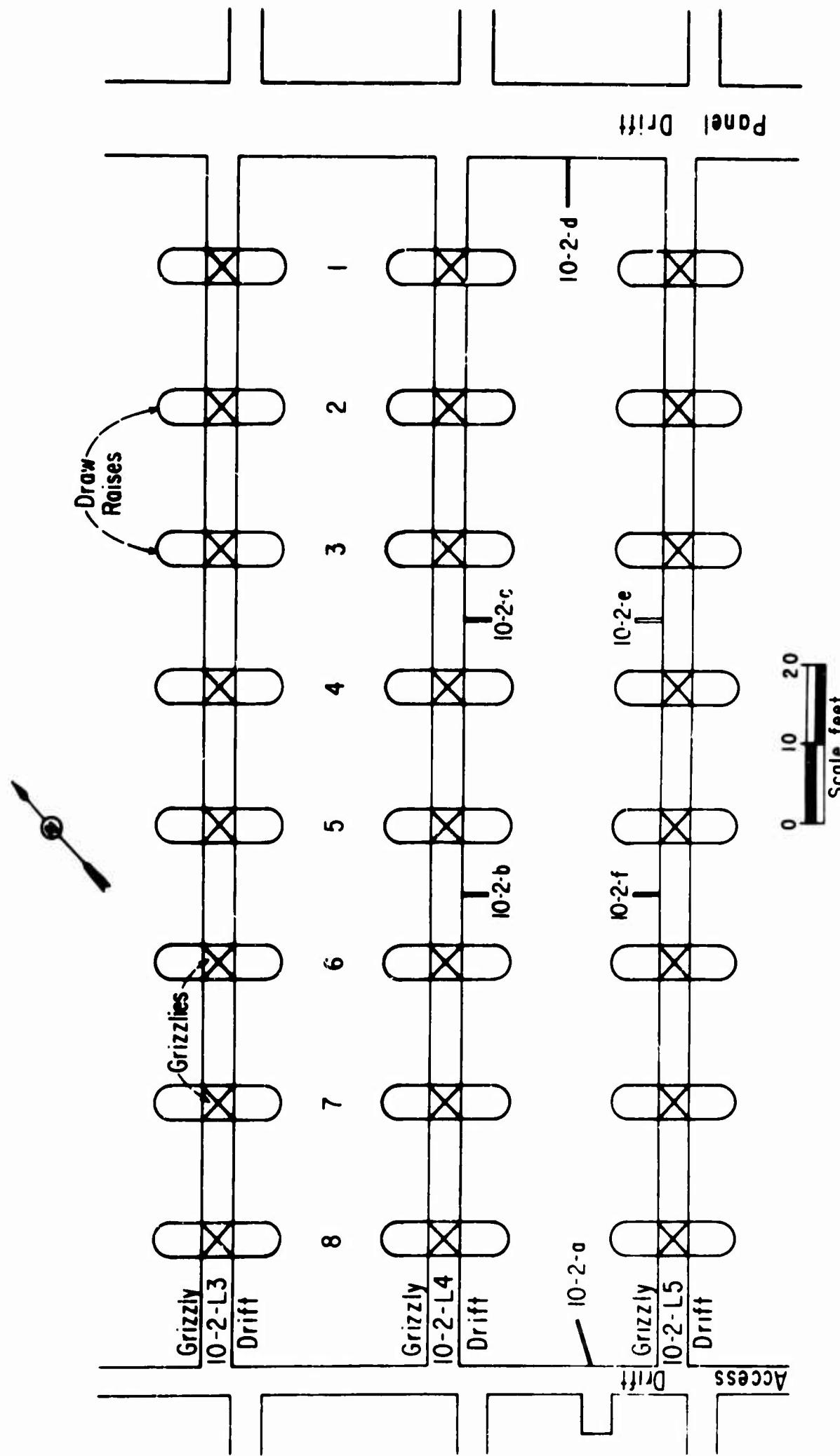
FIGURE 25.-Schematic Plan of a Portion of 10-2 Block, 2015 Level, San Manuel Mine Showing Locations of Sonic Stations.

55

the screen is optimized by increasing the puller pressure, as necessary, at the transmitter and then at the receiver. Elapsed travel time through rock is measured as a distance on the screen from the beginning of the sweep to the point of tangency where the first arrival signal curves away or breaks from the horizontal trace.

Oscilloscopes which can expand the display of a small portion of the screen may be read with greater accuracy through use of a time-mark-generator. This type of calibration-standard produces spikes on the screen at regular time intervals commencing with the beginning of the horizontal sweep as zero when properly plugged into the oscilloscope. The spike (representing a known time interval from zero sweep time) found to be ahead of and nearest to the first arrival signal is placed to coincide with the zero grid line when the display is in the expanded setting. When (without change of sweep time settings) the TMG input to the scope is replaced by the receiver signal, (with proper triggering) the time from the sweep origin to the first arrival added to the elapsed time represented by the selected spike is the total signal travel time.

Colorado School of Mines Experimental Mine Tests

Tests at Idaho Springs were conducted at intervals during a year and results compared. No significant changes were expected in readings since no major mining activity has taken place in decades nor is there any ground settling in progress.

IMC Mine Tests

Tests at IMC were repeated, where possible, a number of times through the year, and results compared.

In addition to tests for equipment and range, a test for pillar soundness was attempted with Model F-IV units and Model IV pulse generator. A 6-foot high sylvite-halite pillar 27 feet by 27 feet in plan, was chosen on the 900 Level. The pillar has been undergoing progressive loading over a period of several years, which has caused some spall fractures to appear on the pillar walls. Depth to which spalling may exist was not known.

An array of holes was drilled into the pillar as shown in section in figure 23. Hole depths (1, 3, 5 and 9 feet) are in increments of 2 or 4 feet, which allowed push tubes to be assembled for each hole by addition of 1-foot 11-inch tube segments joined with 1-inch slip-on couplings.

The test consisted of measuring the time of the first arrival between opposing holes or between the surface and the bottom of the opposite hole, and computing the sonic velocity. Measurement of distance between the holes was made using, for reference, plumb bobs which were hung some distance in front of each line of holes. Distance between plumb bobs was determined by survey. Sound portions of the pillar are considered to have normal velocities, while fractured or spalled sections should show below normal velocities.

San Manuel Mine Tests

All work was conducted on a 2015 Level (grizzly level). Initial tests were made with Model F-II units, which were soon discontinued. All other testing was done with Model F-III units and both pulse generators. Tests for velocity and range were repeated where possible at intervals through the year and results compared.

A number of sites were chosen in sections of the mine where no activity was expected. Other sites were picked where major changes in rock mass stress were expected as a result of major mine activity (undercutting of a caving block). A few stations were placed in or near a major fault zone, in what is considered bad ground.

SECTION VII

RESULTS

General Comments

Model F-II units operated very satisfactorily at Idaho Springs and Carlsbad. The units could not be properly mounted at San Manuel because the rock around the collar of the drill hole would break out as the pressure nut (figure 9, part 22) was tightened.

Model F-III units operated excellently at Idaho Springs and San Manuel, but were not tried at Carlsbad. Under directly comparable conditions at Idaho Springs, Model F-II and Model F-III units transmitted and received equally well.

Model F-IV units work satisfactorily at Carlsbad. Model F-IV units did not have the transmission range of Model F-III units when a direct comparison was made at Idaho Springs. This result was to be expected because of the smaller transducer surface in Model F-IV units.

Pulse generator Models III and IV worked equally well where full power (10 kilovolts) was necessary. No effect in transmission range was noticeable because of the difference in pulse shapes produced by each generator.

Where short range tests were conducted and reduced power was desirable, Model IV generator was definitely more effective.

Colorado School of Mines Experimental Mine

The basic array of stations is shown in figure 20. Transmission between any two stations is essentially across the banding in the gneiss, minor faulting and the majority of joint plane systems. Longest transmission distance is 148.0 feet between Model F-II setups which, although not shown, are adjacent to "A" and "H" which are stations for Model F-III units. Transmission distance between "A" and "H" is 143.5 feet.

Figures 26 through 31 are photographs of typical pulse receptions. Table 2 gives data and velocities for various tests conducted at different times over a year. Velocities are computed assuming a straight line transmission path. Shear wave velocities are computed when recognized, a condition which occurred only for transmission from "C" to "A" or "H", but not for transmission from "A" or "H" to "C". Computation of the dynamic moduli of rigidity and elasticity requires data on the density of material. For a rock mass containing bands of material with appreciably different specific gravities (2.53 to 2.92) the problem of obtaining the density can become complex. No special procedure was used in the present work other than to collect hand samples at nearly regular intervals along the east wall of the Miami Tunnel between stations. Specific gravity was determined for each sample, and the arithmetic average computed for appropriate distances.

The computations that follow hold only for conditions and locations described, with the assumption that the rock mass behaves as an elastic medium when subjected to a transient stress which, in passing through, does not permanently damage any portion of the rock under test. The formulas do not hold, in general, for highly anisotropic media.

For purpose of illustration by using equations (6), (4), (1), (2) and (3), we have the following:

C_b = 15,500 fps ("C" to "A")

C_s = 8,550 fps ("C" to "A")

g = 2.73 specific gravity

m = Poisson's ratio

C_l = Slender bar velocity, fps

E = Young's modulus of elasticity, psi

Y_b = Stiffness modulus, psi

59
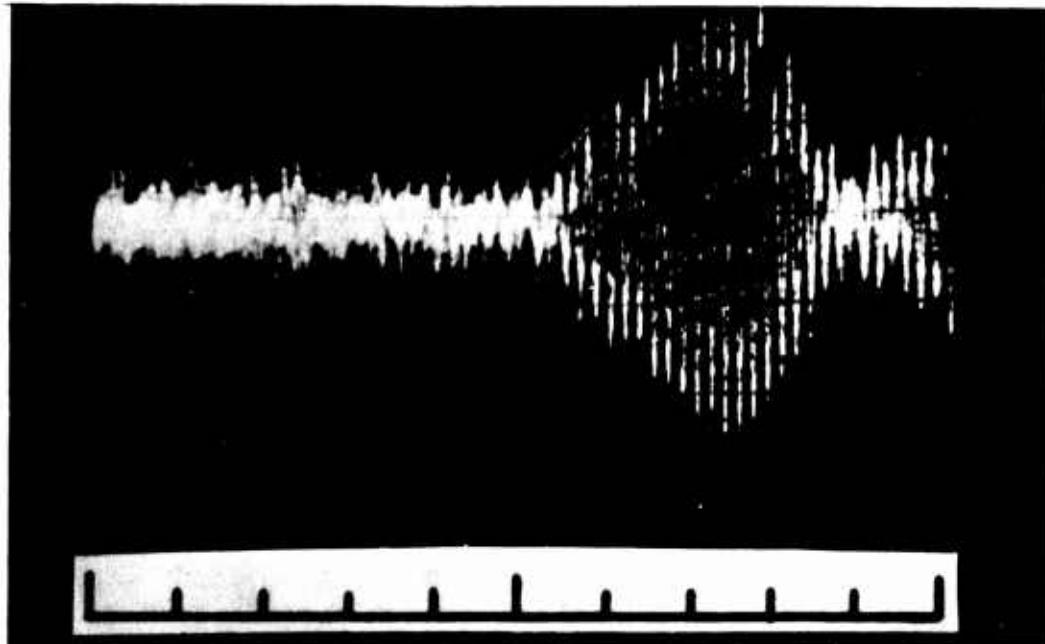
a. Illustration of a Fair Signal.
Horizontal scale: 2.0 msec/division
Vertical scale: 0.05 v/division
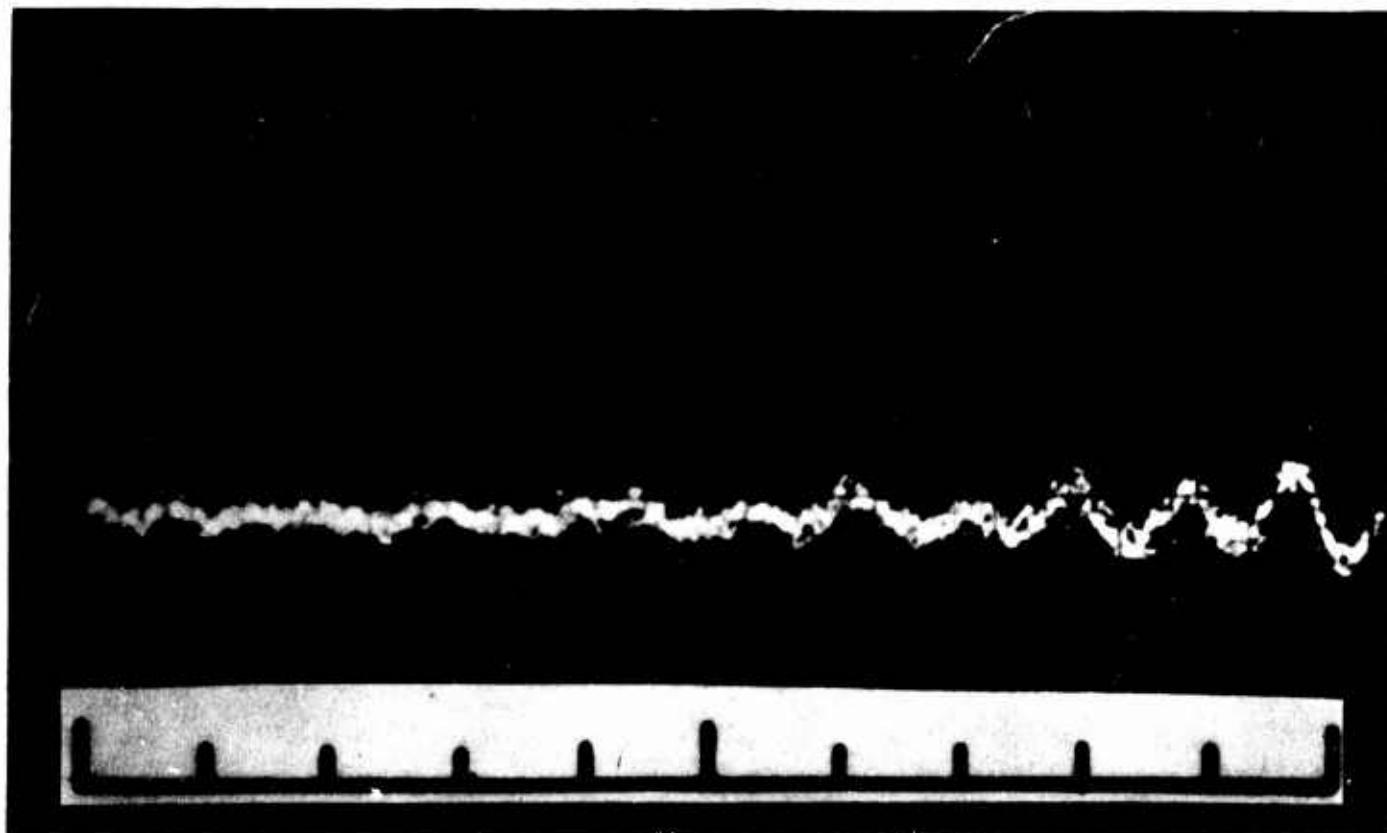
b. Expanded arrival; Central Graticule Line is 10 Missiseconds.
Horizontal scale: 0.4 msec/division
Vertical scale: 0.1 v/division

Figure 26. Oscillograms; CSM Experimental Mine,
Receiver F-III at "H", Transmitter F-III at "A".

60
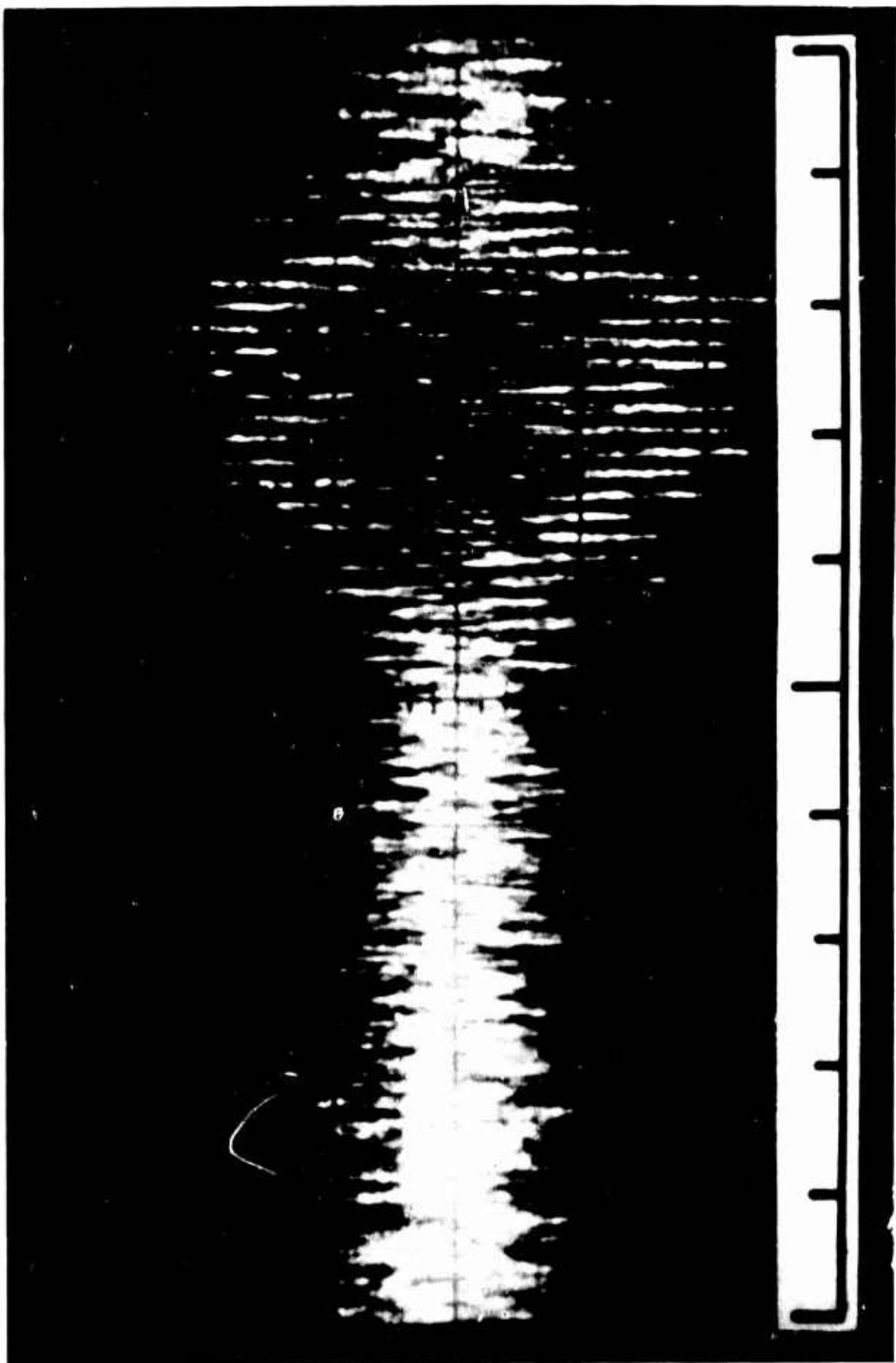
Figure 27. Oscillogram: CSM Experimental Mine, Receiver F-III at "A", Transmitter F-III at "H" Illustration of a Poor Signal.
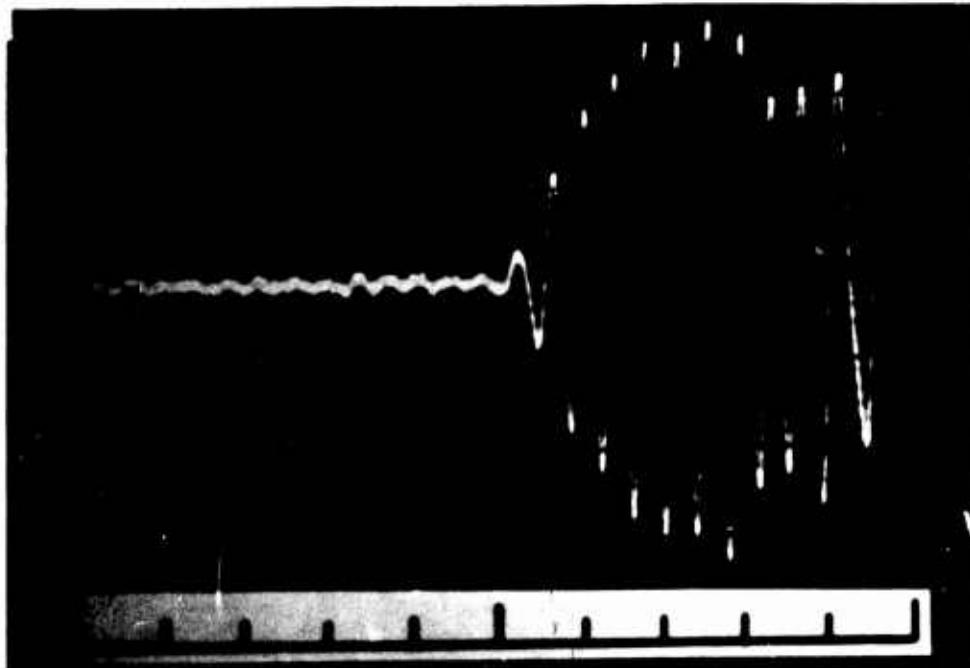
a. Illustration of a Good Signal. Spurious Sound
Wave Appears Along Horizontal Trace.
Horizontal scale: 1.0 msec/division
Vertical scale: 0.2 v/division
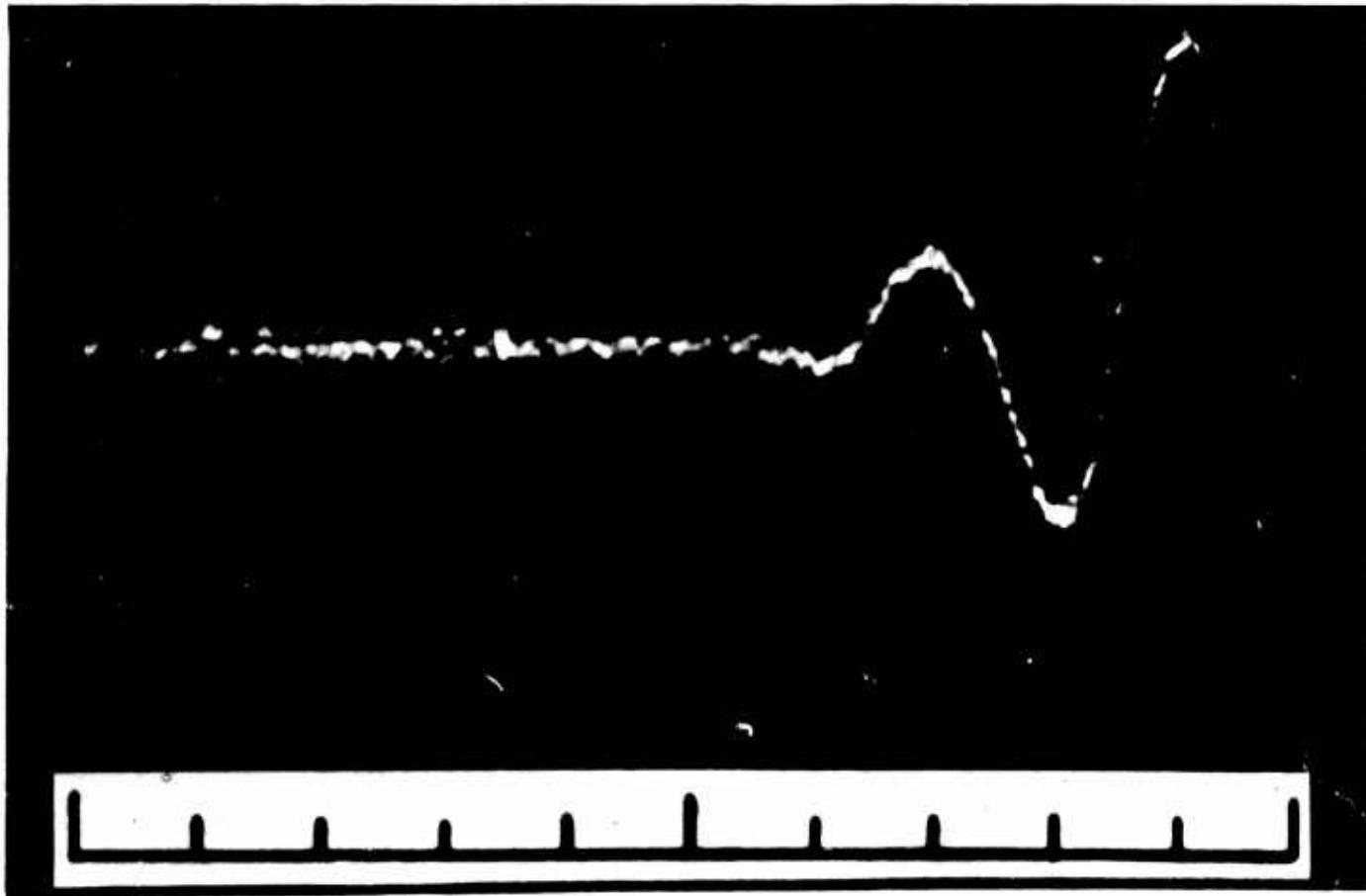
b. Expanded Arrival; Central Graticule Line is
5 Milliseconds. Spurious Sound in Figure "a" no
Longer in Existence.
Horizontal scale: 0.2 msec/division
Vertical scale: 0.1 v/division

Figure 28. Oscillograms: CSM Experimental Mine,
Receiver F-II at "CP, Transmitter F-III at "A".
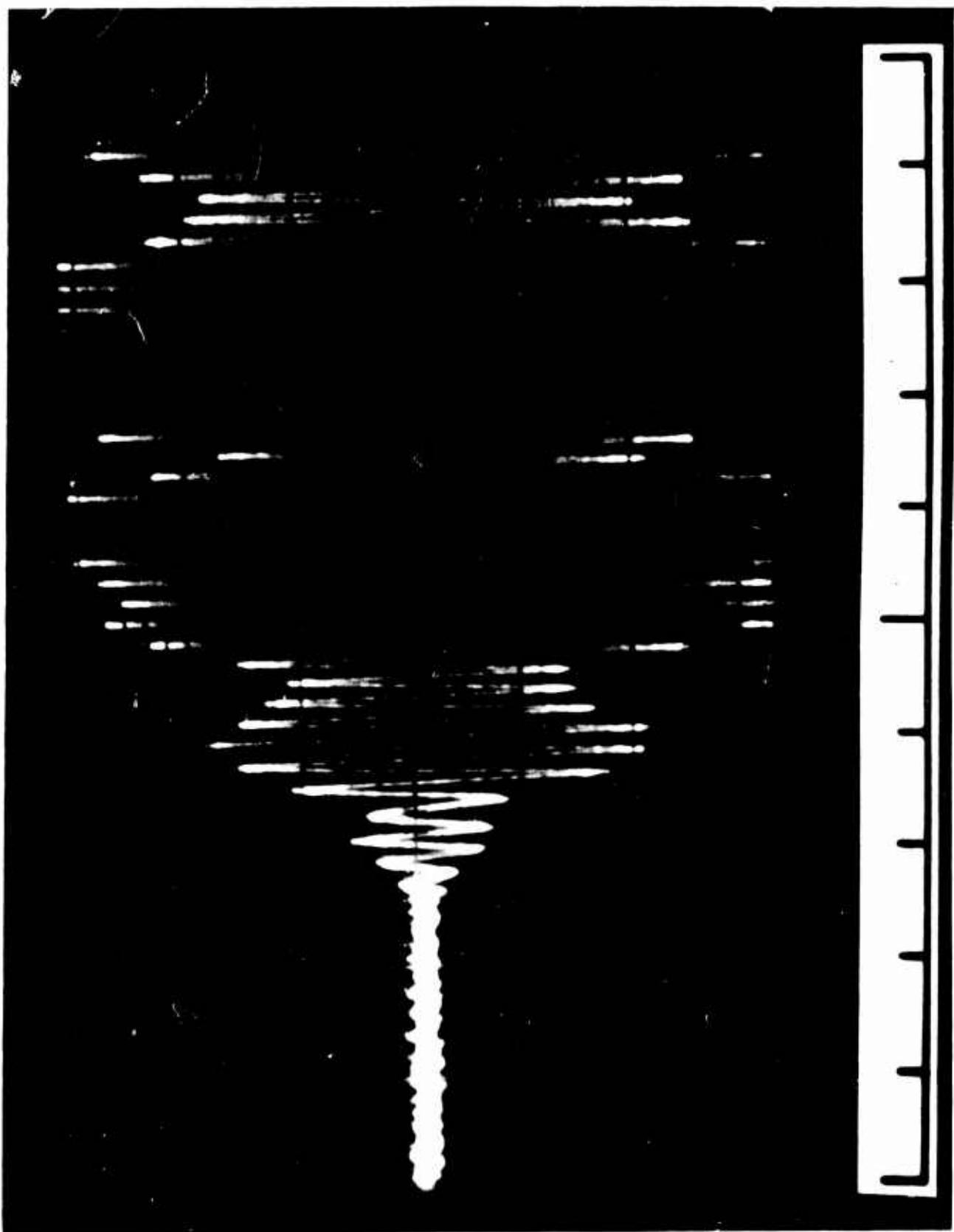
Figure 29. Oscillograms: CSM Experimental Mine, Receiver F-III at "A", Transmitter F-II at "C".
Horizontal scale: 2.0 msec/division
Vertical scale: 0.2 v/division
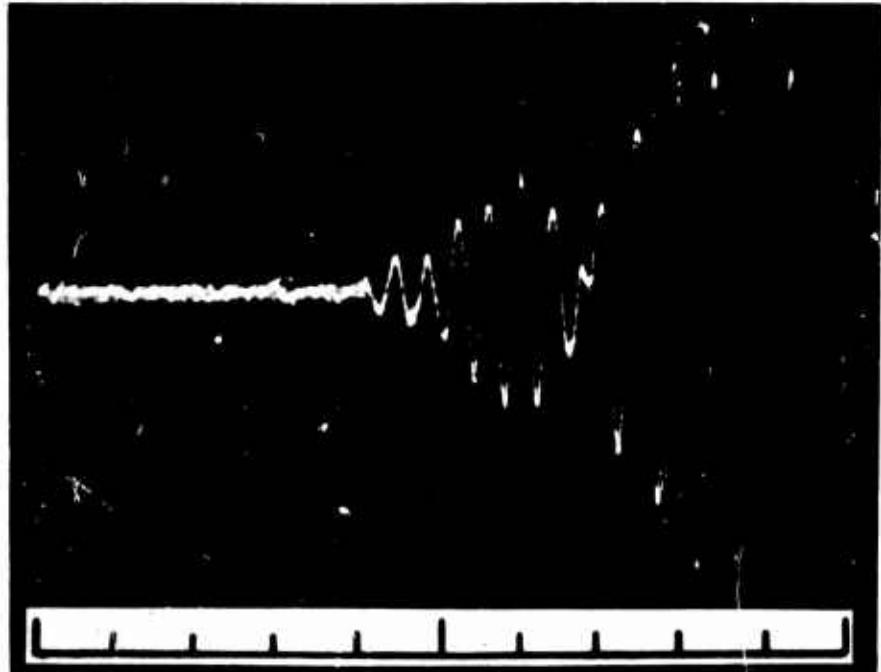
a.   Illustration of a Good Signal.
Horizontal scale: 1.0 msec/division
Vertical scale: 0.2 v/division
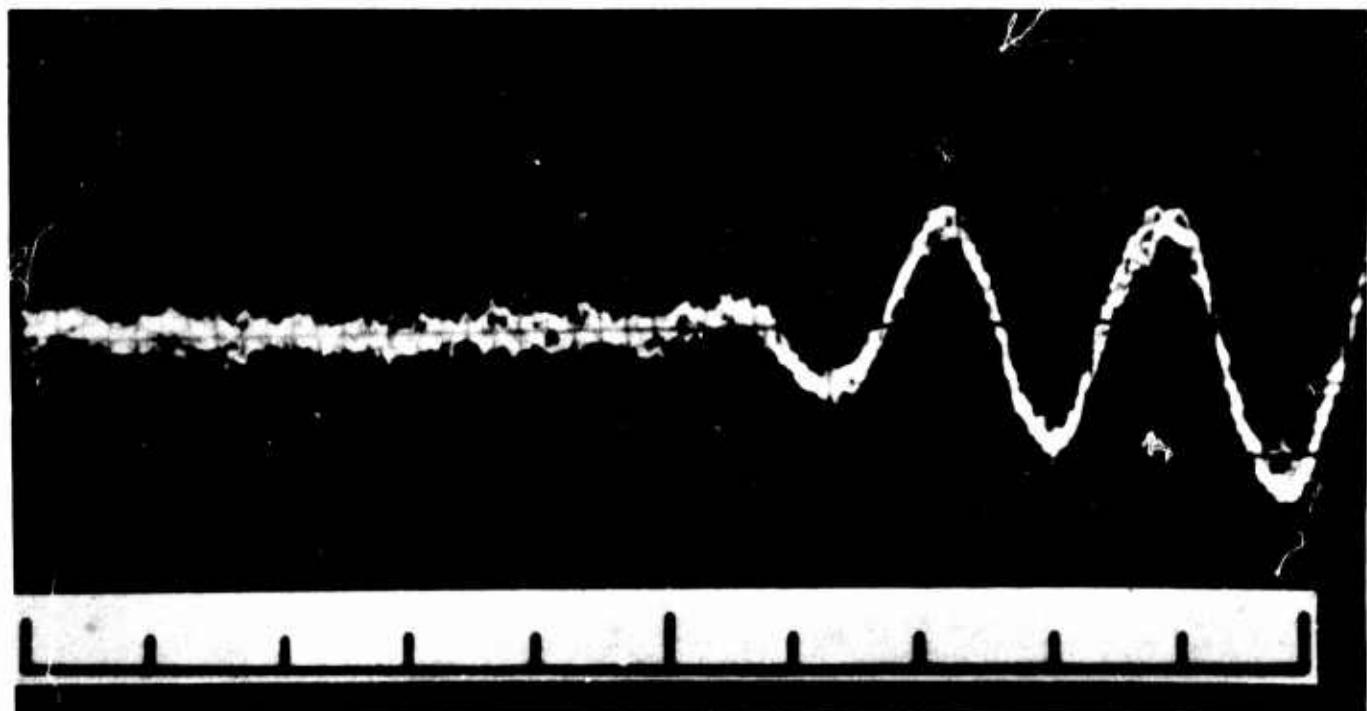
b.   Expanded Arrival;   First Graticule Line is 3 Milliseconds.
Horizontal scale: 0.2 msec/division
Vertical scale: 0.1 v/division

Figure 30.   Oscillograms: CSM Experimental Mine,
Receiver F-III at "H", Transmitter F-II at "C".

64
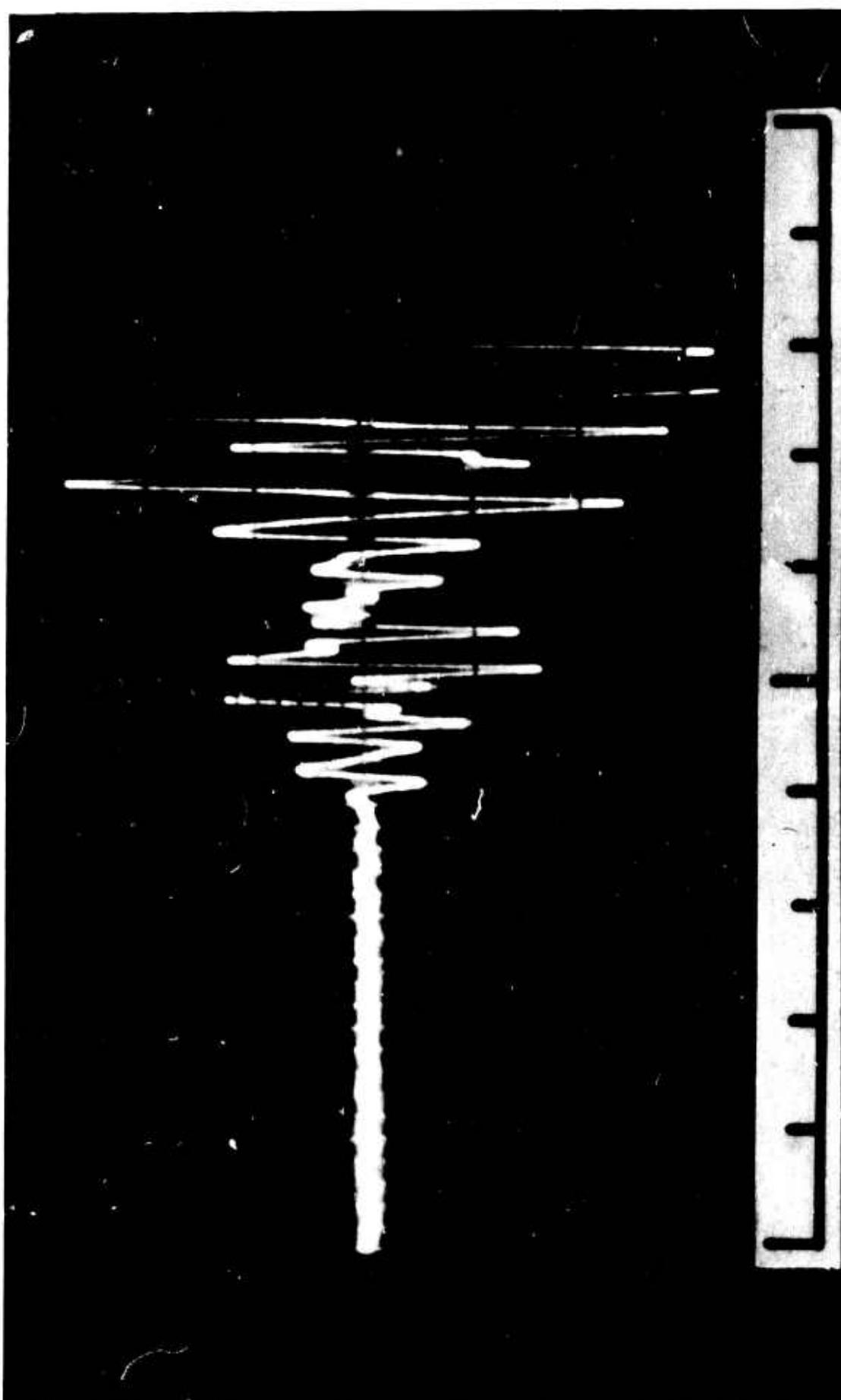
Figure 31. Oscillogram: CSM Experimental Mine, Receiver F-II at "CP, Transmitter F-III at "H".
Horizontal scale: 1.0 msec/division
Vertical scale: 0.2 v/division

TABLE II. - Colorado School of Mines Experimental Mine
Sonic Velocity Tests

| Transmitter model and station	Receiver model and station	Distance, feet	Time, [1] milliseconds		Velocity, feet/second		Signal Quality	Date
			First arrival	Shear wave	First arrival	Shear wave		
F-II A	F-II H	148.0	10.0	---	14,800	---	Good	07/30/64
F-II A	F-III H	145.7	9.9	---	14,700	---	Water pipe noise disturbance	12/5/64
F-III A	F-III H	143.5	9.4	---	15,250	---	Water pipe noise disturbance	12/5/64
F-III A	F-III H	143.5	9.6	---	14,950	---	Good	02/3/65
F-III A	F-III H	143.5	9.68	---	14,800	---	Fair	06/16/65
F-III H	F-III A	143.5	9.6	---	14,950	---	Good	02/3/65
F-III H	F-II A	143.5	---	---	---	---	Very poor signal, cause unknown	06/16/65
F-III A	F-III C	80.5	5.00	---	16,100	---	Good	06/16/65
F-II C	F-III A	80.5	5.20	9.4	15,500	8,550	Good	05/5/65
F-III C	F-II H	65.0	3.96	6.9	16,400	9,400	Good	05/5/65
F-III H	F-II C	65.0	3.96	---	16,400	---	Good	06/16/65

1/ Times to one decimal place were read directly off the screen; times to two decimal places were read with TMG and expanded arrival on the screen.

66

Y_s = Shear modulus (modulus of rigidity)

$$m = \tfrac{1}{2}\left(1 - \frac{C_s^2}{C_b^2 - C_s^2}\right) = 0.28$$

$$C_\ell = C_b\sqrt{\frac{(1+m)\,(1-2m)}{1-m}} = 13{,}687 \text{ fps}$$

$$d = \frac{62.4}{32}\ g = 5.32 \text{ slugs/cu. ft.}$$

$$E = \frac{C_\ell^2}{144} = 6.92 \times 10^6 \text{ psi}$$

$$Y_b = \frac{C_b^2}{144} = 8.88 \times 10^6 \text{ psi}$$

$$Y_s = \frac{C_s^2\,d}{144} = 2.70 \times 10^6 \text{ psi}$$

Table III gives Y_b, E, Y_s and m for various segments of rock mass.

TABLE III - <u>CSM Experimental Mine - Results</u>

Rock segment	Specific gravity	C_b fps	C_s fps	Y_b psi x 10^6	E psi x 10^6	Y_s psi x 10^6	m
A H	2.69	14,950	-	8.14	-	-	..
C A	2.73	15,500	8,550	8.88	6.92	2.70	0.28
C H	2.63	16,400	9,400	9.58	7.90	3.15	0.26

IMC Mine

The majority of the tests on equipment performance was done in a longwall block as shown in figure 21. Layout for a long range test is shown in figure 22. Figure 23 shows a vertical section of a pillar tested for soundness.

Transmitter and receiver were in all cases located in the same stratigraphic zone consisting of a sylvite-halite mixture between beds of barren halite. Transmission was, therefore, essentially parallel to the bedding, and propagation paths used for computation were assumed to be straight lines. The bed is remarkably homogeneous in structure and texture. No vertical or steep faults, joints, or other fissures (with the exception of crystal boundaries) were noticed at the test sites. As a result, transmission losses from crossing such boundaries are practically nil, particularly when compared to the rock masses at Idaho Springs and San Manuel. Transmission range is con' quently far greater in the sylvite-halite at Carlsbad.

Longest transmission distance attained was 1,373 feet as shown on figure 22. A photograph of the signal received is shown in figure 32.

Table 4 is a summary of data and results of tests performed over a period of several months. Signal quality was uniformly very good. For many tests, pulse intensity used was well below the maximum available. Sonic stations as laid out in the longwall block (figure 21) provide a variety of ranges from 108 to 471 feet, with transmitting and receiving units oriented in various ways with respect to each other.

With F-II or F-III transmitting and receiving units mounted co-linearly and facing each other, in general (including other rock types tested), only the first arrival is identifiable in the signal received. With Model F-IV units mounted in the same manner in rock salt, the received signal shows both the compressional (first arrival) and shear wave in a clearly recognizable manner (figure 33a).

No investigation has been made into the apparent difference in behavior of Model F-IV units. The tentative explanation is that the comparatively thick aluminum plate used as a diaphragm is in part responsible for producing a much greater proportion of shear waves at the transmitter-salt interface than is the case with the thin diaphragmed F-II and F-III transmitters.

If F-IV units are mounted at right angles to each other and with some angle (from 0 to 90 degrees) between transmitter axis and line of
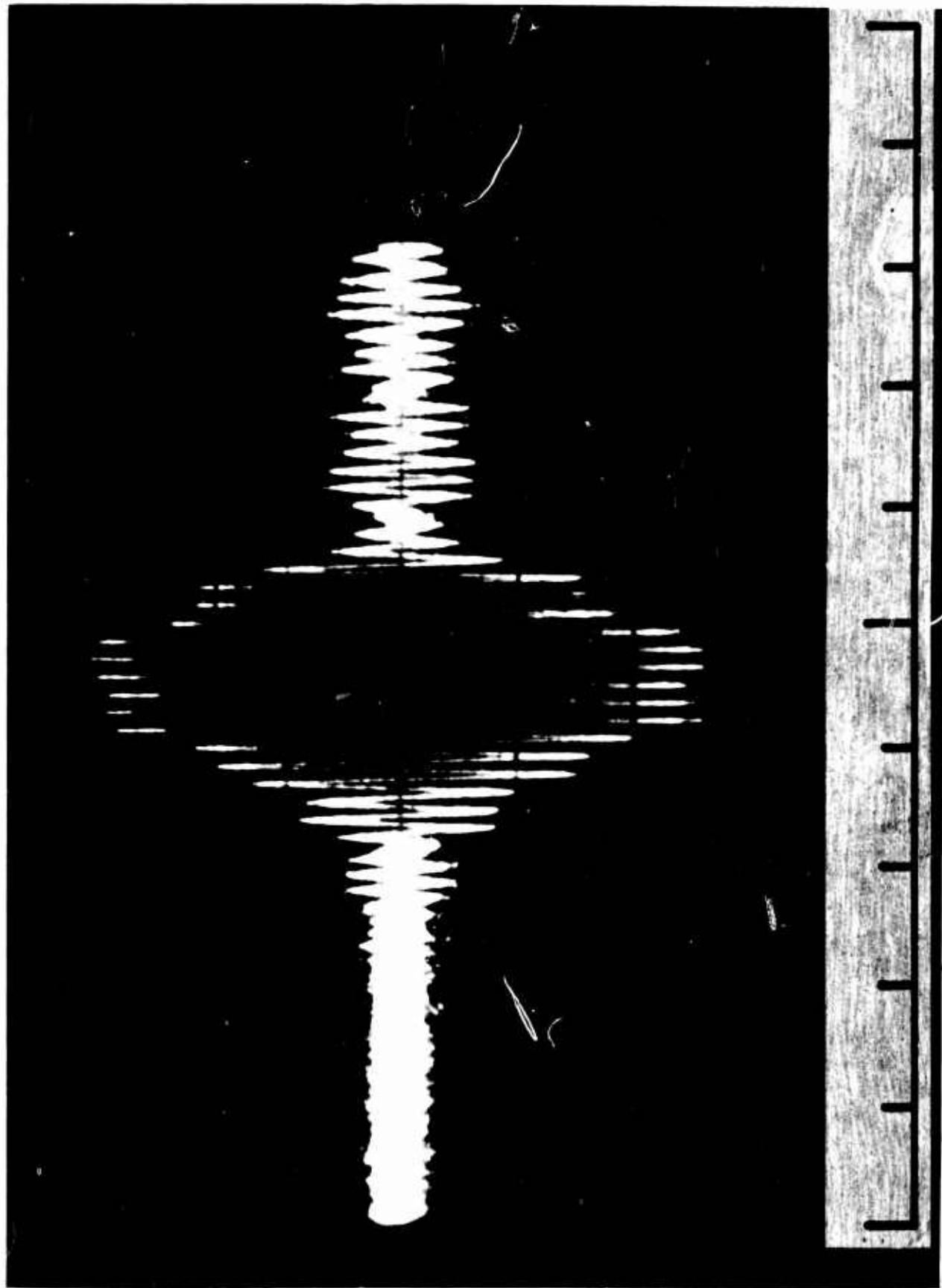
Figure 32. Oscillogram: IMC Mine, F-IV Units, Long Range Test, Transmitter at 1, Receiver at 2, figure 22. Expanded Arrival; First Graticule Line is 90 Milliseconds. Horizontal scale: 2.0 msec/division. Vertical scale: 0.3 v/division Pulse Generator IV at High Output. Camera Time Exposure: 7 seconds.
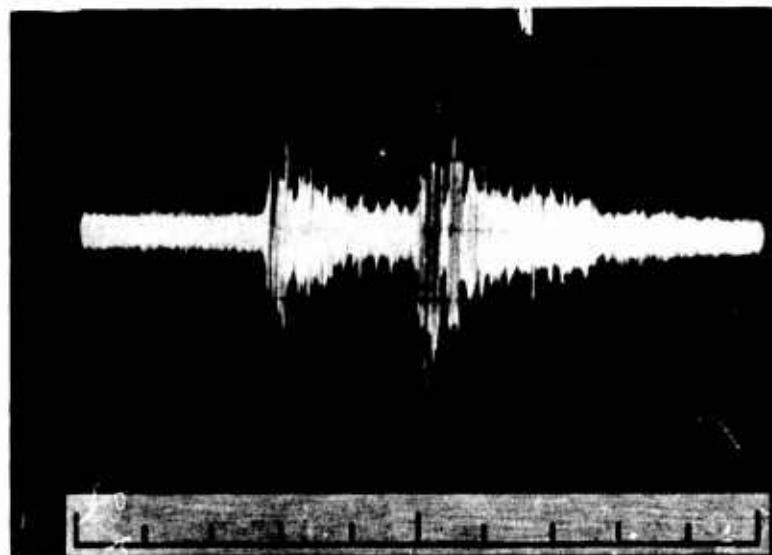
a.

Horizontal scale:
 7.35 msec/division
Vertical scale:
 1.0 v/division
Pulse Generator IV
 at Medium Output

b.
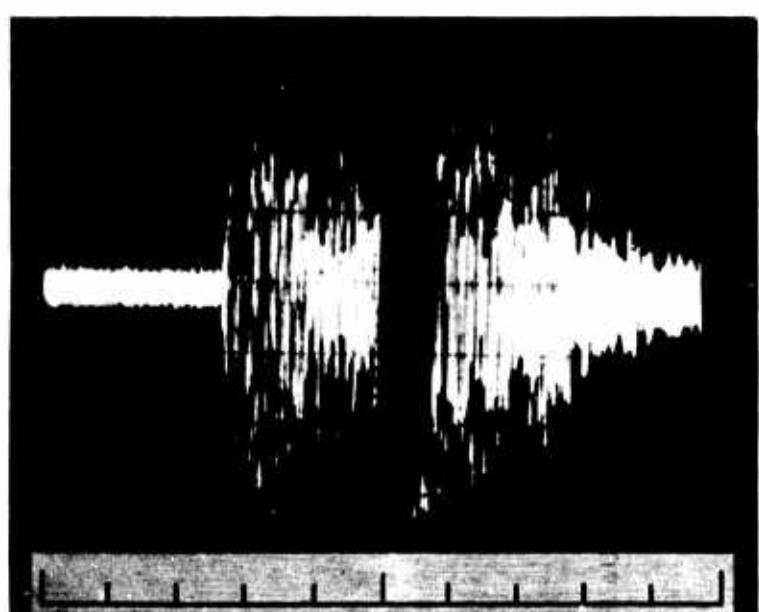
Horizontal scale:
 7.35 msec/division
Vertical scale:
 1.0 v/division
Pulse Generator IV
 at High Output

c.
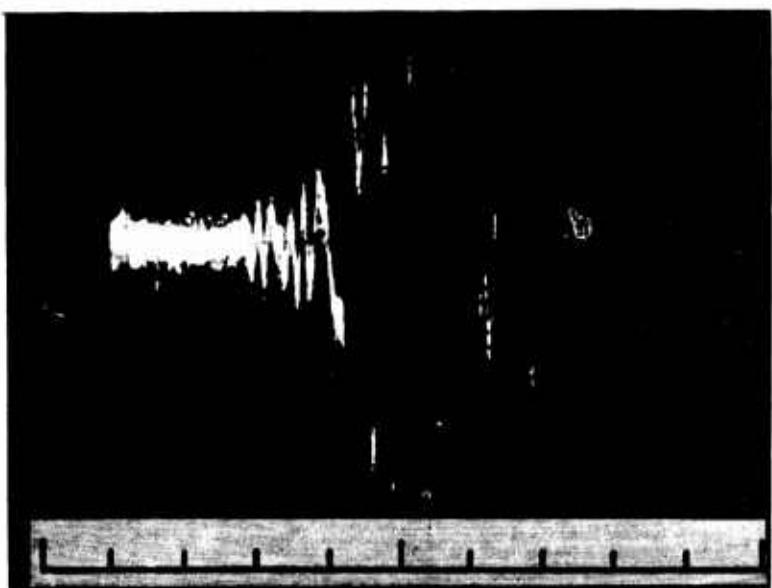
Horizontal scale:
 0.4 msec/division
Vertical scale:
 1.0 v/division
Pulse Generator IV
 at High Output

Figure 33.   Oscillograms: IMC Mine, F-IV Units, Transmitter at 4N-42,
          Receiver at D-1-41.   Units Face Each Other.
Arrival of Compressional and Shear Wave Fronts are Shown Clearly.

70

TABLE IV - IMC Mine, Sonic Velocity Tests, Data and Results

| Transmitter model and station	Receiver model and station	Distance, feet	Time, milliseconds First arrival	Time, milliseconds Shear wave arrival	Velocity, feet/second First arrival wave	Velocity, feet/second Shear wave	Stiffness Modulus Y_b psi x 10^6	Modulus of elasticity E psi x 10^6	Poisson's ratio	Date
F-II 4N-32	F-II D-1-34	288.5	19.6	----	14,700	----	6.16	----	----	08/21/64
F-IV 4N-42	F-IV D-1-41	288.5	19.8	----	14,600	----	6.04	----	----	12/12/64
F-IV 4N-42	F-IV D-1-41	288.5	19.8	37.3	14,570	7,730	6.04	4.43	0.30	12/14/64
F-IV 4N-42	F-IV D-1-41	288.5	19.64	37.0	14,690	7,800	6.14	4.51	0.30	02/19/65
F-II D-1-400	F-II 4N-405	286.5	19.5	----	14,700	----	6.14	----	----	08/25/64
F-II 4N-32	F-II D-1-400	471	32.5	----	14,500	----	5.98	----	----	08/25/64
F-IV 4N-150	F-IV D-1-41	308	21.0	38.0	14,670	8,110	6.12	4.79	0.28	02/22/65
F-IV 4N-150	F-IV R-18-262	300	20.98	37.5	14,300	8,000	5.81	4.63	0.27	02/22/65
F-II 4N-255	F-II 4N-405	150	10.6	18.5	14,150	8,100	5.69	4.69	0.26	08/25/64
F-II 4N-32	F-II 4N-405	373	26.0	44.5	14,350	8,380	5.85	4.96	0.24	08/25/64
F-IV 4N-150	F-IV 4N-42	103	7.60	12.8	14,210	8,440	5.74	4.97	0.23	02/25/65
F-IV 4N-150	F-IV R-18-81	168.5	11.84	21.0	14,230	8,020	5.76	4.63	0.27	02/22/65
F-IV, Long Range 1	F-IV, Long Range 2	1,373	94.80	No show	14,480	----	----	----	----	02/24/65
F-IV, Long Range 1	F-IV, Long Range 2	1,373	94.40	No show	14,540	----	----	----	----	02/25/65
F-IV, Long Range 2	F-IV Range 2	1,373	94.00	No show	14,600	----	----	----	----	02/24/65

1/ Times to one decimal place were read directly off the screen; times to two decimal places were read with TMG and expanded arrival on screen.

2/ Much spurious sonic noise from conveyor belt 130 feet from receiver.

71

sonic propagation from transmitter to receiver (shots 4N-150 to R-18-262, and 4N-150 and R-18-81, figures 21 and 34) the results are essentially the same as if the units were colinear and facing each other. By comparison, the effect which this configuration has on Models F-II and F-III is not clear yet. As previously mentioned, the condition was noted at Idaho Springs where shear waves were recognizable (figu re 20) for C to A and C to H shots (angle between transmitter axis and line of sonic propagation is near 90 degrees) but not for A to C and H to C shots (angle near 0 degrees).

When F-IV units are mounted on rock salt with axes parallel but not colinear, as when mounted some distance apart on the same straight wall (figure 21, stations 4N-405, 4N-255, 4N-150, 4N-42, 4N-32) the signal received shows a compressional wave which is generally weak in comparison with shear wave (figure 35, a, b, c, d).

A study of the photographs shows that the compressional wave or first arrival could be overlooked, and only the shear wave arrival would be seen, if too weak an input pulse were used. With sufficiently strong pulse the beginnings of the compressional and shear waves were quite clear (figure 35, d). Model F-II units in salt perform in the same manner. In rocks other than salt, F-II and F-III perform in the same general way, but results are not as consistently clean-cut or clear.

A colinear, face-on, F-IV transmitter-receiver configuration was used for the long range transmission (figure 22). The signal received showed a first arrival (figure 32) but no shear wave was found in the portion of the screen where expected, in contrast with shorter shots (4N-42 to D-1-41, 288.5 feet) where the same configuration was used.

A pillar which had been under some load for a few years was tested for depth of spall fractures (figure 23). Two vertical arrays of horizontal holes measuring 1, 3, 5, and 9 feet, respectively, from top to bottom, were drilled face to face. Velocities of first arrival waves obtained and shown in the figure indicate that there was no significant variation in velocity between pairs of holes. From the surface, with transmitter at points T_5 and T_6 to hole R_4 there is a velocity decrease of as much as 13 percent from 14,500 ft/ sec which is maximum velocity in the pillar and which is a common velocity for first arrival, as seen in table 4.

Figure 34. Oscillogram: IMC Mine, F-IV Units, Transmitter at 4N-150, Receiver at R-18-81 Units at Right Angle to Each Other. Vertical scale: 1.0 v/division. Pulse Generator IV at High Output. Horizontal scale: 5 msec/division.
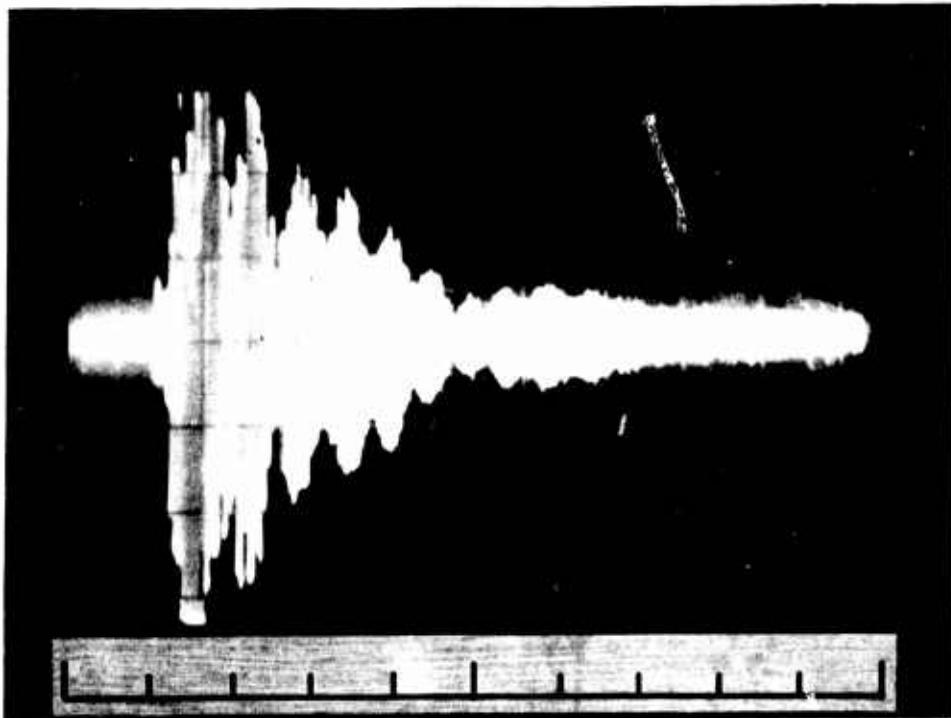
a. Horizontal scale: 10 msec/division
Vertical scale: 1.0 v/division
Pulse Generator IV at Minimum Output.
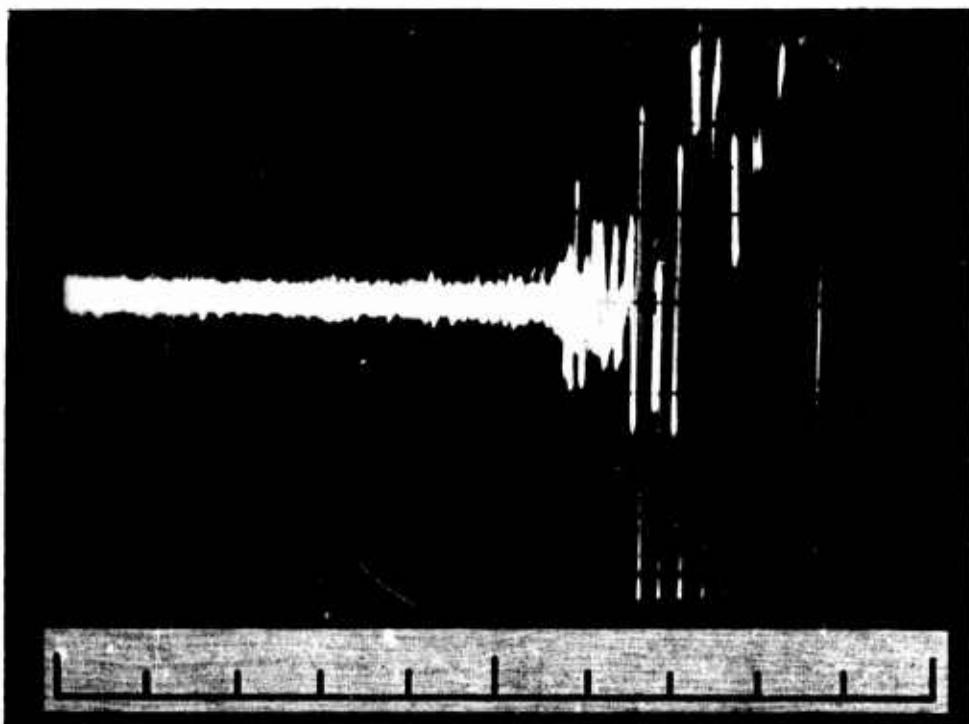
b. Horizontal scale: 2.0 msec/division
Vertical scale: 1.0 v/division
Pulse Generator IV at Low Output

Figure 35. Oscillograms: IMC Mine, F-IV Units, Transmitter at 4N-150,
Receiver at 4N-42 Units Parallel to Each Other but Not Collinear.
Part of Trace on Extreme Left was Missed by Camera;
All Four Photographs Were Taken With the Same Camera Setup.

74
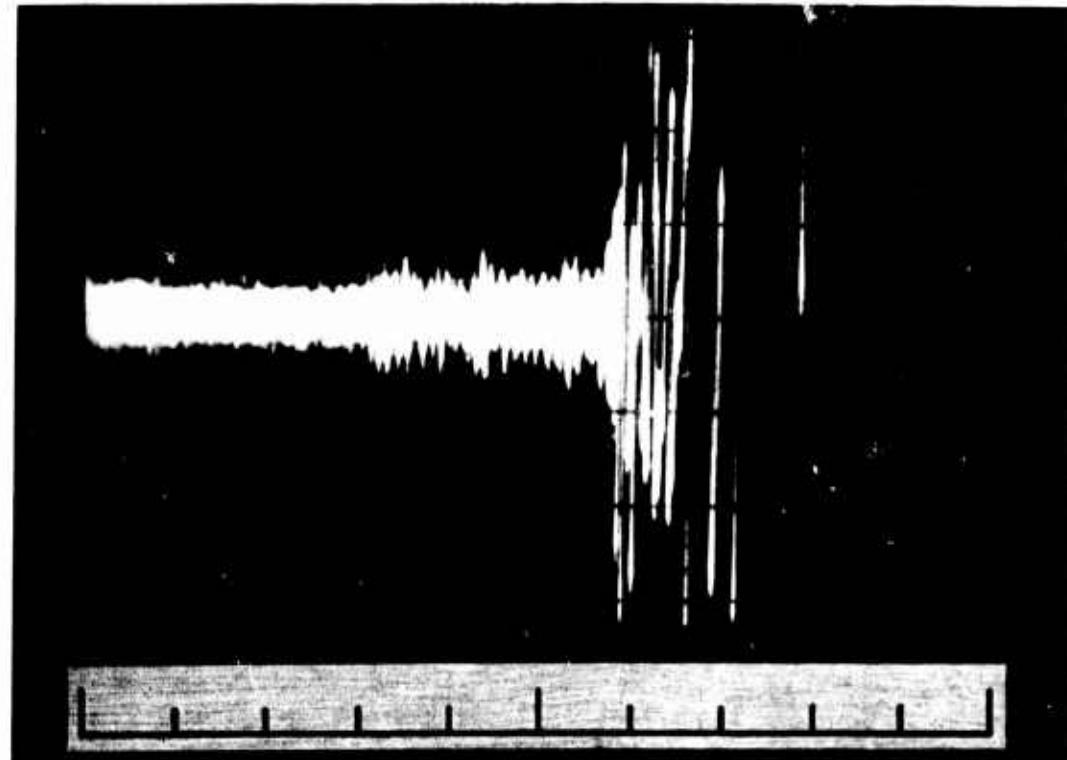
c. Horizontal scale: 2.0 msec/division
Vertical scale: 0.5 v/division
Pulse Generator IV at Medium Output
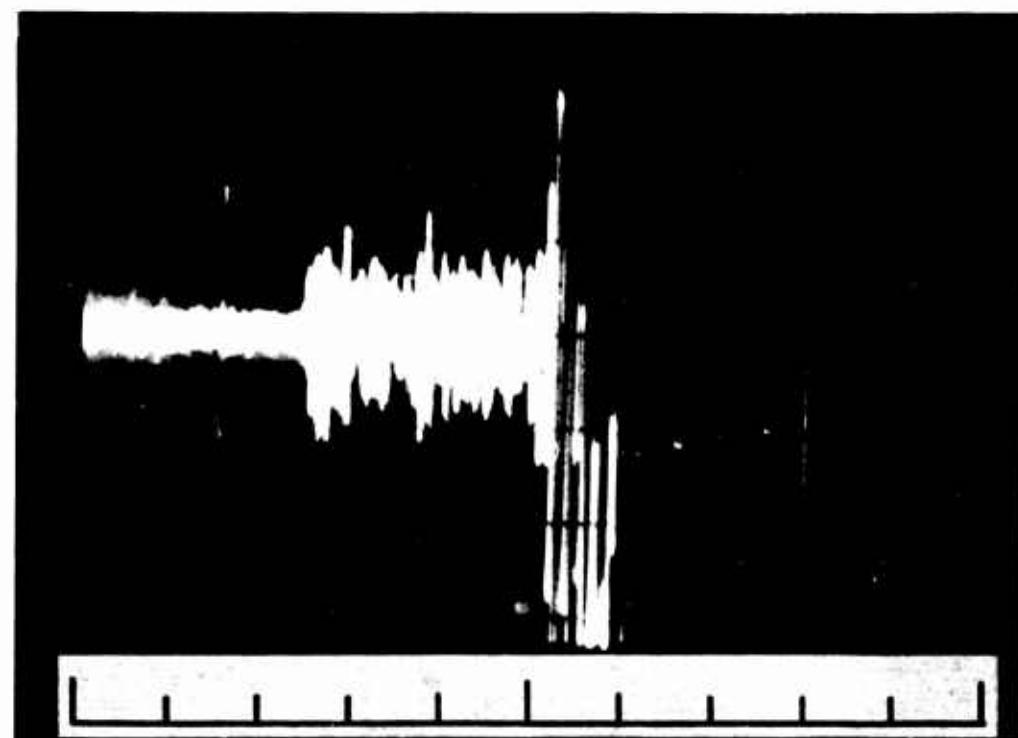
d. Horizontal scale: 2.0 msec/division
Vertical scale: 1.0 v/division
Pulse Generator IV at High Output

Figure 35. (cont'd) Osillograms: IMC Mine, F-IV Units, Transmitter at 4N-150,
Receiver at 4N-42 Units Parallel to Each Other but Not Collinear.
Part of Trace on Extreme Left was Missed by Camera;
All Four Photographs Were Taken with the Same Camera Setup.

Sonic transmission with a handheld transmitter is possible where pulse generator intensity available is ample. In this circumstance, elasto-plastic silicone putty does well as coupling compound between rock face and transmitter, (notwithstanding an unfavorable acoustic impedance matching characteristic) since the putty conforms under light pressure to irregularities of the wall, yet is elastic to fast stress transients. Handheld reception is not practical.

Laboratory experiments with halite-sylvite cores have shown that a considerable reduction in first arrival velocity occurs when spall fractures lie across the line of sound propagation.

The implication of the field test above is that no spalls have formed in the pillar except near the surface, since only transmissions T_5 to R_4 and T_6 to R_4 have shown significant reduction in sonic velocity.

Moduli of stiffness and elasticity and Poisson's ratio are listed in table 4. Specific gravity value used for computation was 2.10, which is the arithmetic average for 10 random pieces of core obtained from various holes drilled in the longwall area. The high and low values, 2.15 and 2.06, represent a spread of 4.5 percent which gives an indication of the homogeneity of the rock bed.

The moduli computed are higher than those obtained by static methods by other researchers. This is to be expected because of the elasto-plastic nature of salt. With short-time stress transients, the rock is elastic; as the time factor is lengthened, plastic behavior is more significant. With geologic time intervals, the salt formations behave plastically.

San Manuel Mine

All tests were performed on the 2015 Level (grizzly level). Most of the stations were located at Panel 13 and Block 10-2, as shown on figures 24 and 25. One pair of stations was located at Panel 12 and another pair was placed on the south edge of Panel 14.

Block 10-2 contains a zone of structurally weak rock material. Stations 10-2-c, 10-2-e, 10-2-d, and 10-2-f, are in or very near a wide approximately northerly trending fault zone, which contains much clayey

TABLE 9. - <u>San Manuel Mine , Sonic Velocity Tests,</u>
<u>Data and Results</u>

Transmitter model and station	Receiver model and station	Distance, feet	Time, [1] milliseconds		Velocity, feet/second		Signal Quality	Date
			First arrival	Shear wave	First arrival	Shear wave		
F-II Panel 14 Drift	F-II S. Fringe Drift	30.0	2.90	4.95	10,340	6,060	Good	09/2/64
F-III Panel 13-b	F-III Panel 13-g	19.0	1.80	-	10,560	-	Good	12/19/64
Panel 13-b	Panel 13-g	19.0	1.80	-	10,560	-	Good	12/21/64
Panel 13-b	Panel 13-g	19.0	2.050	-	9,270	-	Good	02/13/65
Panel 13-b	Panel 13-g	19.0	1.950	-	9,740	-	Good	05/13/65
Panel 13-b	Panel 13-g	19.0	1.95	-	9,740	-	Good	05/13/65
Panel 13-d	Panel 13-e	19.0	1.45	-	13,100	-	Good	12/19/64
Panel 13-d	Panel 13-e	19.0	1.40	-	13,570	-	Good	12/21/64
Panel 13-d	Panel 13-e	19.0	1.440	-	13,190	-	Good	02/13/65
Panel 13-d	Panel 13-e	19.0	1.46	-	13,010	-	Good	05/13/65
Panel 13-f	Panel 13-c	19.0	1.568	-	12,120	-	Good	02/11/65
Panel 13-c	Panel 13-f	19.0	1.560	-	12,180	-	Good	02/13/65
Panel 13-c	Panel 13-f	19.0	1.56	-	12,180	-	Good	05/13/65
Panel 13-b	Panel 13-a	38.0	2.750	-	13,820	-	Good	02/12/65

TABLE V. - San Manuel Mine, Sonic Velocity Tests, Data and Results (Cont.)

Transmitter model and station	Receiver model and station	Distance, feet	Time, 1/ milliseconds		Velocity, feet/second		Signal Quality	Date
			First arrival	Shear wave	First arrival	Shear wave		
F-III	F-III							
Panel 12-L15 D 6-7S	Panel 12-L16 D 6-7N	19.0	1.40	-	13,570	-	Good	12/19/64
Panel 12-L15 D 6-7S	Panel 12-L16 D 6-7N	19.0	1.40	-	13,570	-	Good	12/21/64
Panel 12-L15 D 6-7S	Panel 12-L16 D 6-7N	19.0	1.750	-	10,860	-	Good	02/13/65
Panel 12-L15 D 6-7S	Panel 12-L16 D 6-7N	19.0	1.80	-	10,550	-	Good	02/17/65
Panel 12-L15 D 6-7S	Panel 12-L16 D 6-7N	19.0	1.850	-	10,270	-	Good	05/13/65
Panel 12-L15 D 6-7S	Panel 12-L16 D 6-7N	19.0	1.88	-	10,110	-	Good	05/13/65
Block 10-2-c	Block 10-2-e	19.0	2.580	-	7,360	-	Fair	02/15/65
Block 10-2-c	Block 10-2-e	19.0	2.60	-	7,310	-	Fair	02/16/65
Block 10-2-c	Block 10-2-e	19.0	2.60	-	7,310	-	Fair	03/18/65
Block 10-2-b	Block 10-2-f	19.0	1.74	-	10,920	-	Good	02/15/65
Block 10-2-b	Block 10-2-f	19.0	1.776	-	10,700	-	Good	02/15/65
Block 10-2-b	Block 10-2-f	19.0	1.736	-	10,940	-	Good	02/16/65
Block 10-2-b	Block 10-2-f	19.0	1.74	-	10,920	-	Good	02/16/65
Block 10-2-b	Block 10-2-f	19.0	1.76	-	10,800	-	Good	03/18/65
Block 10-2-b	Block 10-2-c	35.0	7.00	13.70	5,000	2,550	Fair	02/17/65
Block 10-2-b	Block 10-2-e	40.0	7.60	-	5,260	-	Weak	02/17/65
Block 10-2-a	Block 10-2-b	55.3	9.20	-	6,010	-	Weak	02/15/65
Block 10-2-a	Block 10-2-f	54.7	7.20	-	7,600	-	Poor	02/16/65
Block 10-2-d	Block 10-2-c	53.0	No signal	-	-	-	No signal	02/17/65

1/ Times to two decimal places were read directly off the screen; times to three decimal places were read with TMG and expanded arrival on the screen.

78

fault gouge and rubbly rock. Stations 10-2-a and 10-2-b are in better ground.

Stations located in Panels 13 (figure 24), 14, and 12 (not shown) are in structurally stronger rock material than above.

Model F-II units were mounted in the rock mass with difficulty, as mentioned previously in the report. Only the test in Panel 14, listed at the beginning of table 5, was considered successful. The remainder of the tests listed in table 5 (Data and Results) were carried out with Model F-III units in 72-inch and 42-inch holes. These holes were drilled through not less than 1-1/2 feet of concrete which lines the walls of grizzly drifts, panel drifts, and access drifts in which the holes were located. All holes were bottomed in rock with possibly one exception.

Longest distance transmitted was 55.3 feet located in Block 10-2. Variations in the rock mass from place to place are of such magnitude that maximum transmission ranges are quite variable. Transmission from 10-2-c to 10-2-e (figure 25) was through 19 feet of clay gouge and rubble, which is probably the maximum effective range in this type of material with the equipment as described. The rock mass in Panel 13, L15 to L16 area, has much better transmission qualities, as indicated by the magnitude of the signals received. Although the longest distance transmitted was 38.0 feet, transmission ranges 60 feet or greater could be expected here.

Inspection of first arrival velocities in the table shows a low of 5,000 feet per second in the fault zone area, and a high of 13,570 feet per second in Panel 13, which is a marked contrast in velocities between bad and good ground or between structurally weak material and reasonably solid rock mass. These data support laboratory data from other investigations that, in general, correlation exists between high sonic velocity and high structural strength and between low velocities and low strengths.

The rock mass in which the stations shown on figure 24 were placed was not subjected to any major stress changes caused by mining during the period of time shown by the dates in table 5. No significant changes in velocity were recorded, with one possible exception. Transmission 13 to 13-g showed some change which could have been caused by a

partially unsatisfactory coupling pad at 13-b.

Stations located in Panel 12 (east of Panel 13) in lines 15 and 16 between draw raises 6 and 7 (12-L15, D 6-7S, and 12-L16, D 6-7N, table 5) were in a zone affected by mining. First readings (19 and 21 of December 1964) were taken as the block undercutting operation at the undercut level (15 feet above the grizzly level) was nearing, but had not reached a point directly over the stations. At that time, a mounting stress concentration was developing in the rock mass surrounding the stations. Subsequent readings (February 13, 1965) were taken after the undercut operation was completed and the stress concentration had been relieved. Inspection of the table shows a marked decrease in velocity from 13,570 feet per second to 10,860 feet per second followed by a more gradual decrease with time.

Figures 36, 37 and 38 from tests in Block 10-2 area are photographs that show respectively good, fair, and weak signal receptions. Figure 36, the reception from a face-on transmitter-receiver configuration, shows a clear first arrival notwithstanding the existence of considerable spurious low-frequency mine operation noise.

Figure 37 shows the reception from a side-by-side (35.0 feet apart) transmitter-receiver configuration from which an interpretation was made of a first arrival compressional wave followed by a shear wave (see table 5). Figure 38 is of doubtful interpretation. Stations 10-2-c, 10-2-d, and 10-2-e, were obliterated by ground movement some time after the first set of readings was taken.

No computations for moduli are included because rock density variations in the rock mass are appreciable, and because no samples considered significant for a given transmission could be collected readily. Dynamic moduli, when computed, should show a considerable difference from static moduli, particularly in fault gouge zones and in weak rock masses which behave much as a semi-plastic substance over periods of time of, perhaps, minutes to months and longer. For these rock masses, dynamic moduli would apply only for very short-time transient stresses.
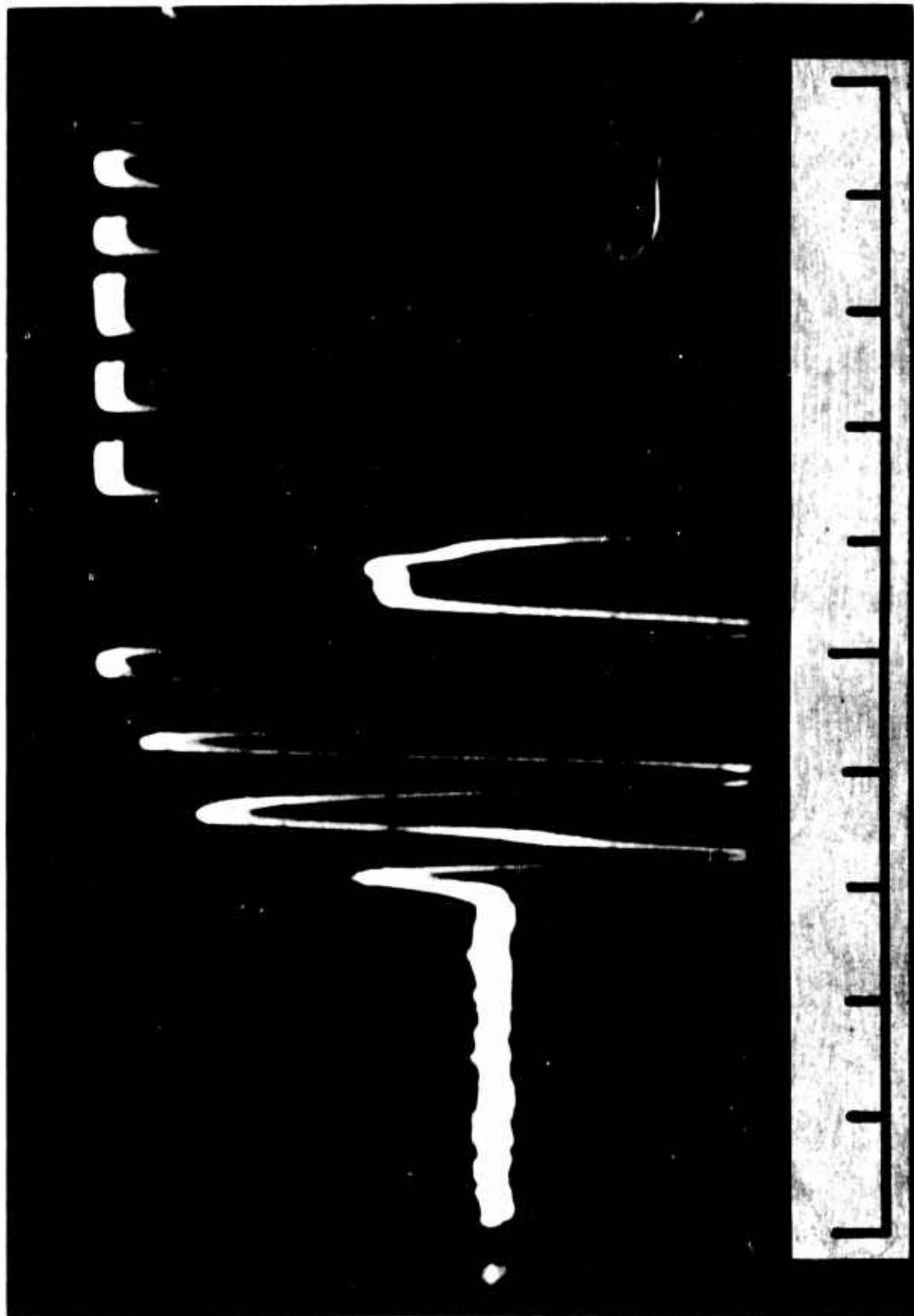
Figure 36. Oscillogram: San Manual Mine, F-III Units, Transmitter at 10-2-b, Receiver at 10-2-f. Units Face Each Other. The Horizontal Scale is Odd Because the Photograph was Taken for Illustration Only. Vertical scale: 0.5 v/division. Camera Time Exposure: 3 seconds. Horizontal scale: 0.61 msec/division.

81
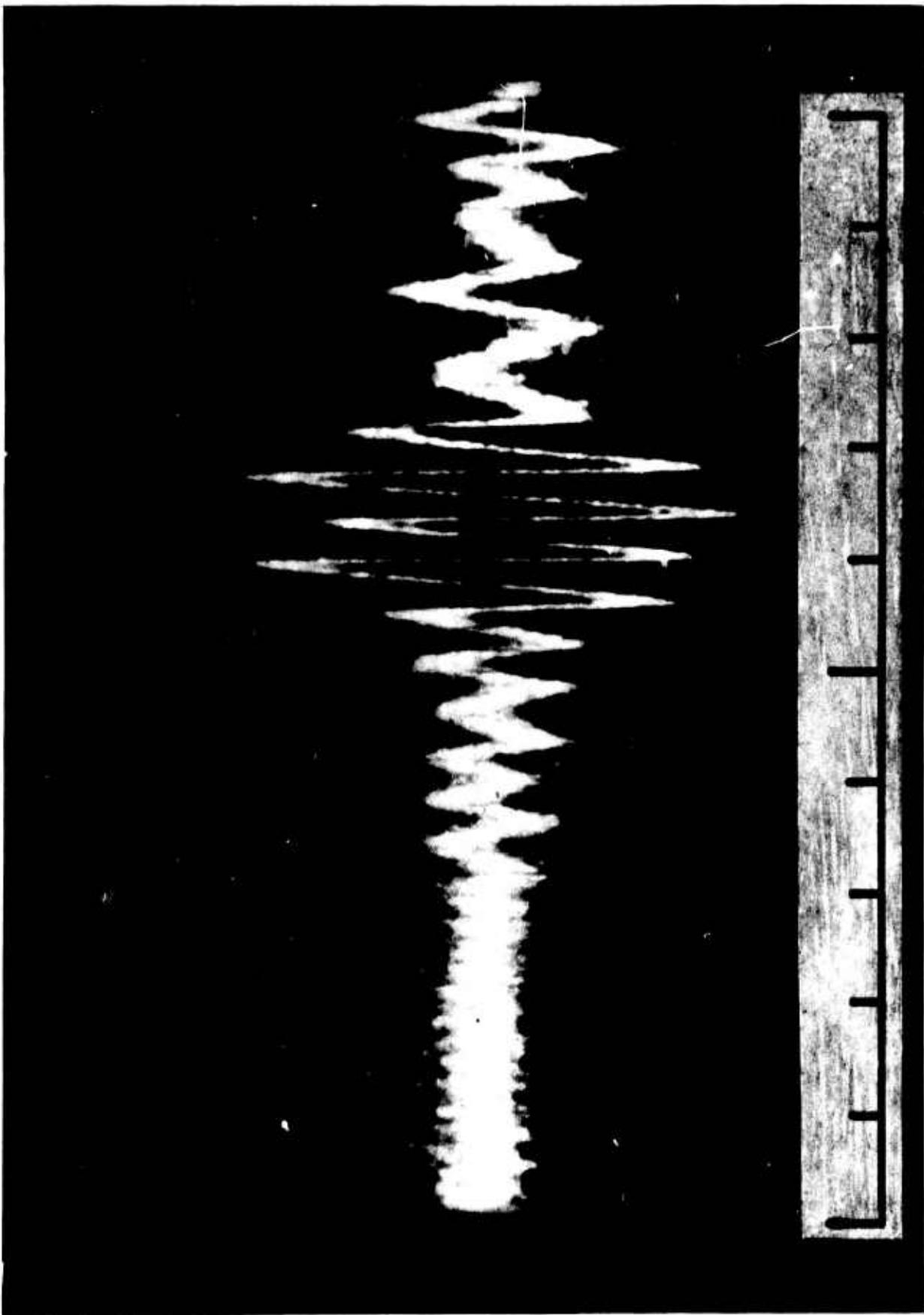
Figure 37. Oscillogram: San Manuel Mine, F-III Units, Transmitter at 10-2-b, Receiver at 10-2-c. Units Parallel to Each Other but Not Collinear. Horizontal scale: 2.69 msec/division. Vertical scale: 0.2 v/division.
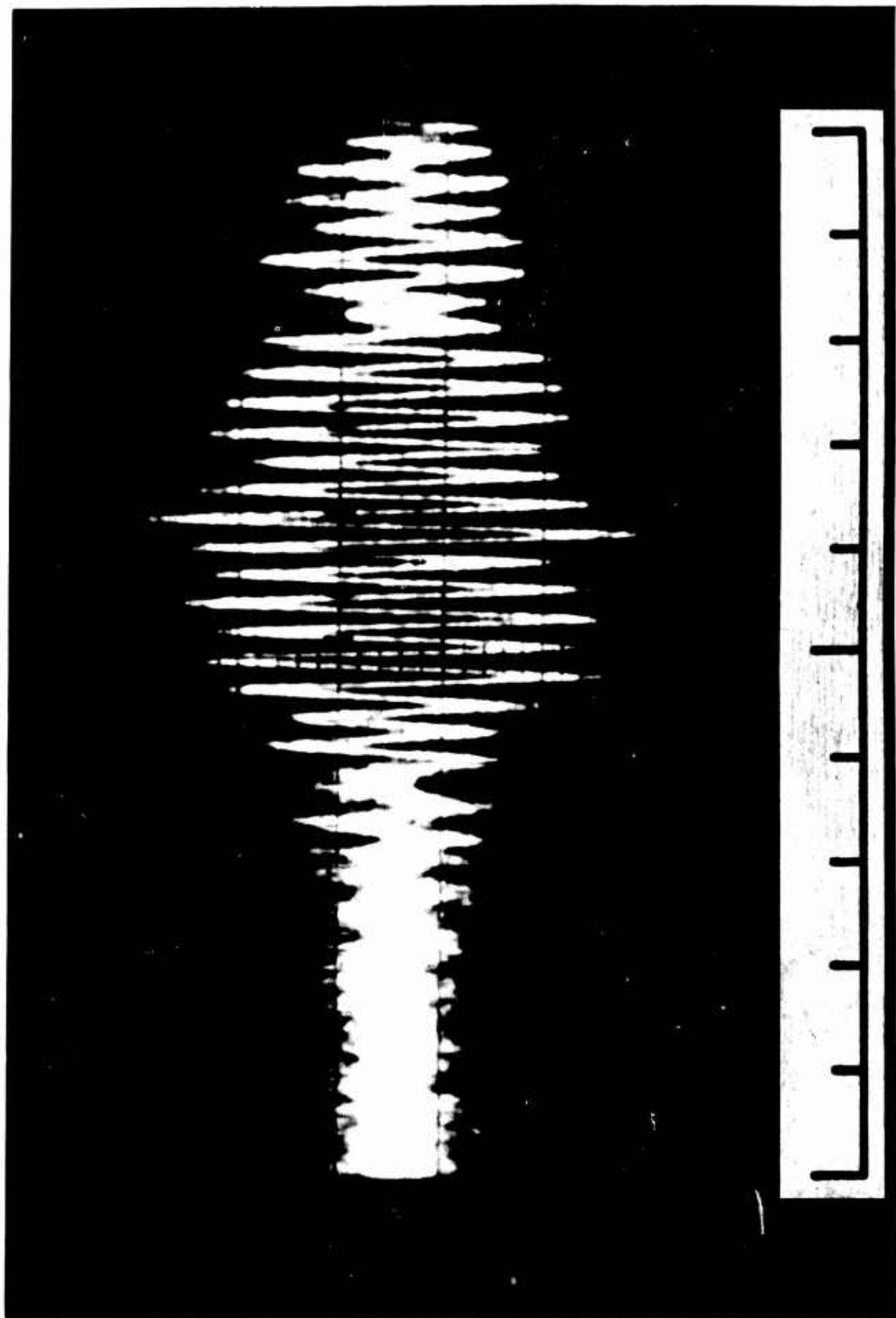
Figure 38. Oscillogram: San Manual Mine, F-III Units, Transmitter at 10-2-b, Receiver at 10-2-e. Units Parallel, Offset, Towards Each Other. Horizontal scale: 3.17 msec/division. Vertical scale: 0.2 v/division.

SECTION VIII

CONCLUSIONS

The electronically controlled, piezo electric pulsing equipment for in situ testing of rock by sonic transmissions, developed by the work described in this report, shows an improvement over earlier versions of similar equipment.

A material reduction in equipment weight and bulk has been achieved. Practical methods of mounting and coupling transmitting and receiving units to rocks with different structural and textural characteristics have been developed. Comparative transmission ranges for granitic gneiss, sylvite-halite, and porphyry-copper ore have been established. Operating ranges attained in each rock type are extensive enough to produce data useful for measurement of dynamic moduli or as an indication of the presence or development of structural damage to the rock mass. Stability and accuracy of the equipment is within the limits set by operator reading error, oscilloscope tolerance, and ordinary short-range ground survey accuracy.

Data obtained indicate that with some modifications the equipment and techniques could be used for the study of pulse-train frequency relative to the transmitting rock medium.

REFERENCES

1. Cannaday, F. X., and G. M. Leo. Piezoelectric Pulsing Equipment for Sonic Velocity Measurements in Rock Samples from Laboratory Size to Mine Pillars. BuMines Rept. of Inv. _____ .

2. Hueter, T. F., and R. H. Bolt. Sonics. John Wiley & Sons, Inc., New York, N. Y., 1955.

3. Eshbach, Ovid W. Handbook of Engineering Fundamentals. John Wiley & Sons, Inc., New York, N. Y. 2ed., 1958.

4. Nichols, Harry R. In Situ Determination of the Dynamic Elastic Constants of Rock. BuMines Rept. of Inv. 5888, 1961.

5. Dale, V. B. Mining, Milling, and Smelting Methods, San Manuel Copper Corp., Pinal County, Ariz. BuMines Inf. Circ. 8104, 1962.

6. Goss, Wesley P. "San Manuel Copper Corporation," Eng. Min. Jour., vol. 150, No. 7, 1949.

7. Schwartz, G. M. Geology of the San Manuel Copper Deposit, Arizona. Geol. Survey Prof. Paper 256, 1953.

8. Peterman, L. A. (Gulton Mfg. Corp.) "Producing Motion with Magnetostrictive and Piezoelectric Transducers." Electrical Manufacturing, Dec. 1955.

9. Jaffe, Bernard "A Primer on Ferroelectricity and Piezoelectric Ceramics." Technical Paper TP-217, Eng. Memo No. 60-14, Dec. 1960, Electronic Research Division, Clevite Corp.

10. Germano, C. P., "On the Meaning of the "g" and "d" constant as Applied to Simple Piezoelectric Modes of Vibration." Technical Paper TP-217, Eng. Memo No. 61-15, July 1961, Electronic Research Division, Clevite Corp.

11. Mason, W. P., Piezoelectric Crystals and Their Application to Ultrasonics. Van Nostrand, New York, 1950.

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13. ABSTRACT Object of the work is development of equipment and techniques for transmission of nondestructive, repetitive, stable, closely controlled-shape sonic pulses through various types of rock in place. Rock masses tested were granitic gneiss schist, potash rich salt beds, and porphyry-copper ore. The tests measure some physical properties of a rock mass over various periods of time. Sonic pulses are produced by electronically excited, piezoelectric-ceramic transducers housed in transmitter and receiver units. Electronic pulses for transducer excitation are generated by transistorized battery-powered pulse generators. Output from receiver units (or geophones), amplified by transistorized preamplifiers, is led into a portable transistorized oscilloscope triggered by the electronic pulse generator to display the signal. Various models of transmitter and receiver units differing in size, weight and manner of insertion into boreholes in rock are described. Two models of electronic pulse generators and a receiving unit preamplifier are described. With exception of the oscilloscope, all major equipment components were developed by U.S. Bureau of Mines facilities. Transmission distances attained varied from 55 feet in strongly hydrothermally altered porphyry copper ore to 1,373 feet in sylvite-halite. Data obtained could be used to compute dynamic moduli of rigidity and elasticity. Under proper conditions, data were obtained that revealed development or presence of permanent rock-structure damage.

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